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MONTHLY WEATHER REVIEW

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U. S. DEPARTMENT OF COMMERCE • WEATHER BUREAU

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First published in 1872, the Monthly Weather Review serves as a medium of publication for technical contributions in the field of meteorology, principally in the branches of synoptic and applied meteorology. In addition each issue contains an article descriptive of the atmospheric circulation during the month over the Northern Hemisphere with particular reference to the effect on weather in the United States. A second article deals with some noteworthy feature of the month's weather. Illustrated. Annual subscription: $3.00; additional for foreign mailing, $1.00; 30¢ per copy. Subscription to the *Review* does not include the *Supplements* which have been issued irregularly and are for sale separately.

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(Continued on inside back cover)

The Weather Bureau desires that the *Monthly Weather Review* serve as a medium of publication for original contributions within its field, but the publication of a contribution is not to be construed as official approval of the views expressed.

The issue for each month is published as promptly as monthly data can be assembled for preparation of the review of the weather of the month. In order to maintain the schedule with the Public Printer, no proofs will be sent to authors outside of Washington, D. C.

The printing of this publication has been approved by the Director of the Bureau of the Budget, February 9, 1955.

DEPARTMENT OF COMMERCE
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SOME LONGER TORNADO PATHS IN ARKANSAS ABOUT A CENTURY AGO

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When Arkansas lands were surveyed a century or more ago, engineers preparing the Federal Land Survey plats for the General Land Office indicated the principal timber falls showing paths of severe local storms through wooded areas of the State. The plats covered the period from 1815 through 1859. Mr. W. E. Headrick, cartographer for the Arkansas Highway Department, examined these plats and plotted the longer length paths of storms. These paths for 1829–1854 are shown in figure 1.

Arkansas is mostly wooded. Paths of these storms were usually indicated on the General Land Office plats as "hurricane paths," showing principal timber falls. These were usually one-fourth mile or less in width, but sometimes up to a mile wide. Although these were called "hurricane paths" over most sections of the State, and "cyclone paths" in the Ozark area of northern Arkansas, it is believed they were actually paths of tornadoes because of their narrow width and general direction from southwest to northeast. The dates of occurrence of these swaths of fallen timber were obtained by the surveyors, when possible, through inquiry of the residents in the area, but the years indicated likely were not always exactly the years of occurrence. For example, the path through Pulaski County, shown as 1829 on the Land Survey plat, likely occurred when a tornado struck Little Rock on May 30, 1830 [1].

Many of the paths cover nearly the same area. In Union County, for example, Mr. Headrick noted that much of two paths in 1844 and 1845 were in exactly the same area. Only a few timber falls are recorded in eastern Arkansas from Arkansas County northeastward, principally because this area is prairie country, or is covered only by bottomland hardwoods.

One feature of particular interest in the paths of several tornadoes in northwest Arkansas is their movement from northwest to southeast with a definite backing tendency, forming a hook as they turned to the northeast. It is also interesting to see that the storms did not always move in a perfectly straight line, although the general orientation of the tracks is from southwest to northeast. These minor variations in direction can possibly sometimes be accounted for by topography; at other times, the change in direction apparently cannot be explained by topographic features.

Figure 1 is of historical interest in showing that tornadoes a hundred years or more ago in Arkansas were much the same as those of recent years [2, 3].* It also is of interest in illustrating a new source of storm data, one that may yield important results if further explored. In this connection it should be pointed out that Mr. Headrick also has plotted many of the tornado paths of recent years. These data, the results of direct surveys by the Arkansas Highway Department, are especially worthwhile because they furnish rather exact information on length of path, direction, and location.

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*Sources of data on tornadoes in Arkansas in recent years are to be found in issues of the *Monthly Weather Review*, and *Climatological Data, National Summary*.

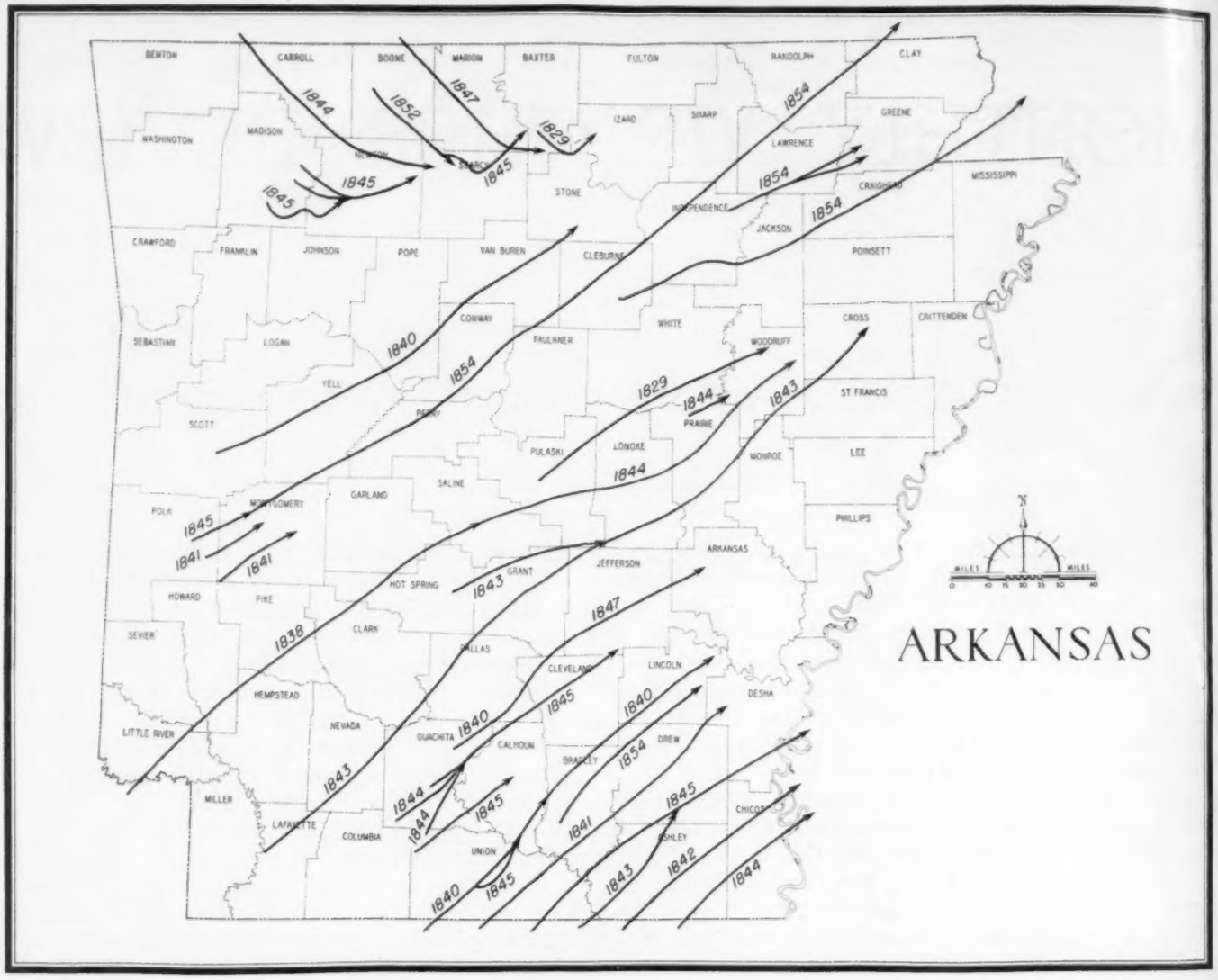

FIGURE 1.—Some longer tornado paths in Arkansas, 1829–54, as shown on Federal Land Survey plats.

A ROCKET PORTRAIT OF A TROPICAL STORM

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[Manuscript Received July 8, 1955]

ABSTRACT

Photographs taken on October 5, 1954, from an Aerobee rocket fired from White Sands, N. Mex., are presented which show the cloud patterns of a tropical storm near Del Rio, Tex., and a secondary vortex over southwestern New Mexico. The method and purpose of obtaining these photographs are discussed.

Detailed surface-pressure and 300-mb. isotach and streamline analyses reveal features of the circulation missed by the usual contour analysis. This illustrates some possible shortcomings of our routine analysis and the utility of rocket photo-reconnaissance.

1. INTRODUCTION

For almost a decade the Naval Research Laboratory of Washington, D. C., has been actively engaged in the field of high altitude photography from rockets. The principal purpose has been to obtain pictures of the earth so that the rocket aspect (its orientation in space during flight) could be determined. To obtain this aspect information it is desirable that recognizable features of the earth's surface be photographed, an objective best attained when there is a minimum of cloud cover. For that reason and because optical tracking from the ground is also desirable, rockets are seldom fired if the cloudiness exceeds 10 percent. Consequently photographs from rockets have not provided much information relative to large areas of clouds.

A fortunate exception occurred on October 5, 1954. Two rocket-borne movie cameras obtained pictures of towering clouds spiraling into a tropical storm near Del Rio, Tex. The pictures may well launch the era of rocket photo-reconnaissance for meteorology. In the near future more rocket pictures of hurricanes will be made, for plans are already going ahead to fire rockets for that specific purpose. Techniques that will be developed by rocket reconnaissance of hurricanes may find wider application in an expanded program of ultra-high altitude meteorological reconnaissance. Dr. Harry Wexler of the U. S. Weather Bureau has discussed the utility of such ultra-high photography in connection with hypothetical synoptic situations [1].

The purpose of the present paper is to present and discuss the photographs taken from the rocket fired from White Sands, N. Mex., on October 5, 1954, and to illustrate their usefulness in analyzing the meteorological situation.

2. ROCKET PHOTOGRAPHY

As a part of the Naval Research Laboratory's continuing research program, two motion picture cameras were flown in a Navy Aerobee rocket, fired from the White Sands Proving Ground, N. Mex., at 1815 GMT on October 5, 1954. At the time of this flight there was a generous scattering of clouds over the area surrounding the launching site. However, because of a large opening in the cloud cover directly above the site, it was decided to fire as scheduled. The result, in addition to aspect information, was the acquisition of a photographic portrait of a tropical storm and one other associated vortex. These pictures mark the first time such a storm has been photographed from an altitude sufficient to show the detailed structure over a large area. In addition the pictures represent the first time the earth has been successfully photographed in its natural color from rocket altitudes.

The pictures were taken by two 16 mm. motion picture cameras mounted in the nose shell of the rocket in a position so as to take pictures perpendicularly to its axis. In this particular flight the nose shell containing the cameras and other scientific equipment was separated from the body of the rocket on the down leg and parachuted to earth. The films and cameras, armored as usual to protect them from impact damage, were recovered in perfect condition.

One of the cameras was equipped with an extremely wide angle lens (90°) and used Super XX black and white film. The camera took 6 pictures a second with an exposure of 1/1500 sec. at f/4.5. Because of the wide field of view the pictures contain an appreciable amount of distortion. The magnitude of this distortion is, however,

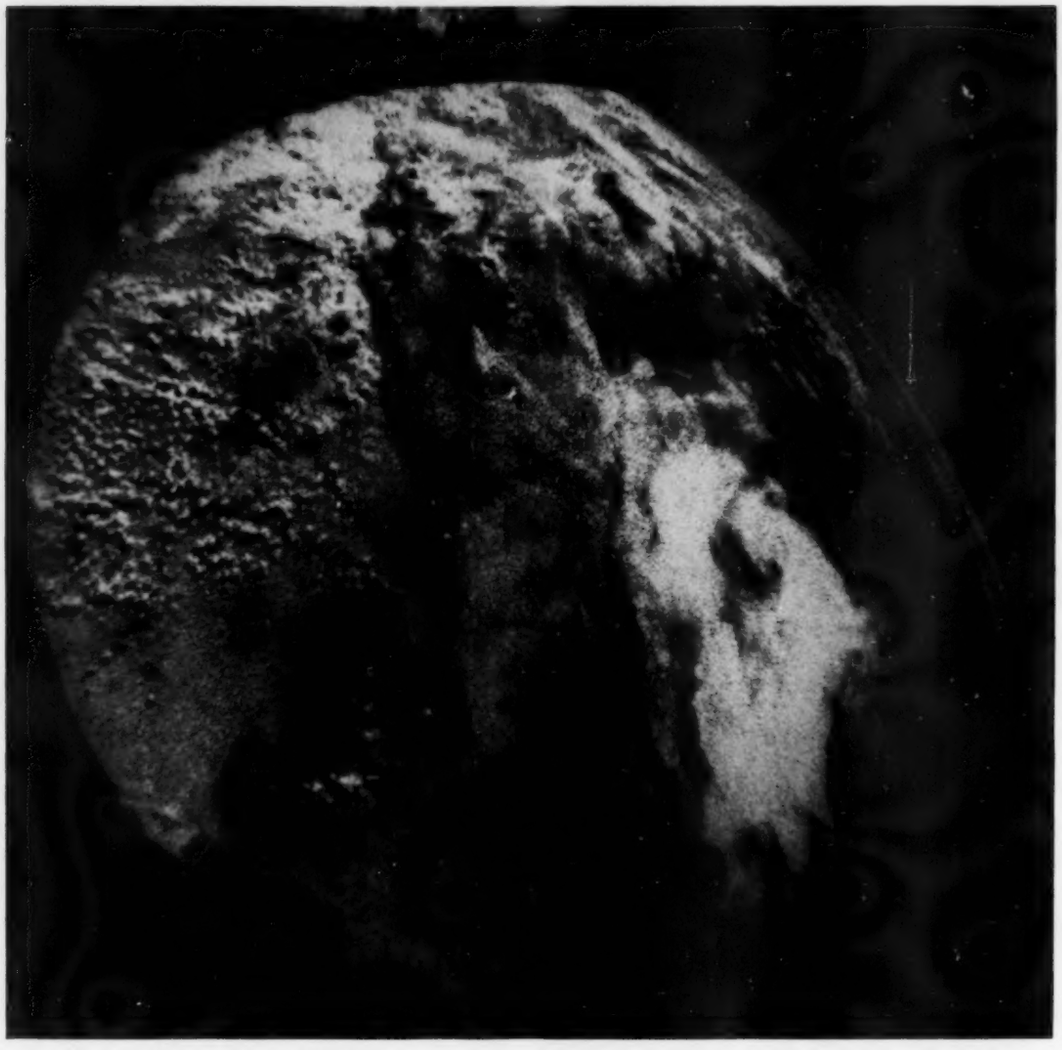

FIGURE 1.—Photograph with 90° lens from altitude of approximately 100 miles over White Sands, N. Mex., showing secondary vortex over southwestern New Mexico.

known. Figure 1 is a frame from this camera showing a vortex which will be discussed later.

The second camera in this rocket was equipped with a semi-telephoto lens and contained Kodachrome film. This camera took 6 pictures a second with an exposure of 1/500 sec. at f/3.5. A Wratten 2B filter was employed to eliminate the blue haze commonly found in color photographs taken from high altitudes.

The flight pattern of the rocket near its summit made it possible to assemble a mosaic from the individual frames of the color film. As the rocket approached its summit 100 miles above the earth it was slowly rolling on its axis and gradually tipping over toward the southeast. As a result, on each roll the camera was scanning successive strips of the earth, each swath overlapping and appearing northwest of the previous one. Figure 2 is a black and white reproduction of the resulting mosaic composed of about 90 enlarged prints from the color film.

Because a semi-telephoto lens was used on the camera, individual enlargements from the color film contain no appreciable distortion. There is however, a small amount of distortion in the composite picture (fig. 2). The distortion resulted from the individual enlargements being mounted on a sphere of too large a radius. This was purposely done so that a single photograph of the mosaic could be taken. It is necessary to mount the individual enlargements on a sphere because the focal surface of the rotating camera is a sphere. For purposes of measurement and location of specific points on the earth's surface, the enlargements were also mounted on a sphere of the correct radius. Figure 3 is a sketch of the area covered by the composite, showing the principal cities and the point from which the pictures were taken.

The mosaic (fig. 2) exhibits an area of one and a quarter million square miles and a horizon length of 2,800 miles. This is the largest area of the earth ever contained in a single picture from effectively one point. The outstanding feature is, of course, the full-area portrait of the tropical storm centered near Del Rio, Tex., in the upper left portion of the picture. A more critical analysis of the

FIGURE 2.—Mosaic composed of approximately 90 frames taken by telephoto lens from altitude of approximately 100 miles over White Sands, N. Mex. The tropical storm is slightly left of upper center and the secondary vortex (shown also in fig. 1) is in lower right. The distortion in this composite is made apparent by comparison with figure 3.

FIGURE 3.—The area pictured by mosaic of figure 2 is outlined by the dashed lines. The apparent discrepancies between mosaic and this diagram are due to the distortion discussed in text. (Note, for example, that the tropical storm in the left upper center of figure 2 is centered near Del Rio, Tex.)

storm and associated clouds can be made from this mosaic as it appears in full color in *Life* magazine of September 5, 1955.

3. METEOROLOGICAL SITUATION

A tropical storm moved westward from western Cuba on October 2 with a central pressure of about 1007 mb. and winds up to 30 knots, and continued across the Gulf of Mexico with little change—it never did develop into a hurricane. On October 4 the center entered the Texas coast some 40 miles north of Brownsville but no surface winds above 18 knots were reported. During passage of this system Brownsville recorded 3.09 inches of rain in 45 minutes and over 6 inches in 3 hours. During the following day the rainfall pattern moving with the storm decreased in intensity, then increased again when the storm moved over the Big Bend region of Texas and the southwestern corner of New Mexico and caused floods in the Roswell, N. Mex., area. At about the time of the New Mexico rains, all traces of a vortex disappeared as an advancing polar air mass invaded the region.

Some provocative characteristics of the circulation are revealed by a detailed analysis of this situation. The words "detailed analysis" are used advisedly, for the smoothing inherent in the routine surface and upper air analysis of the regular data completely obliterates these features. The primary system shown in the upper left portion of figure 2 was one of a family of three vortices over southwestern United States at that time. Figure 5, a streamline analysis of the 300-mb. surface, shows the three systems. To the east, and out of the camera range, is a center near Corpus Christi, Tex. The primary system just northwest of Del Rio is the one shown in the upper part of figure 2, while the westernmost system can be seen at the lower right edge. The radiosonde observation for Del Rio suggests the clouds in the primary system extended to 35,000 to 40,000 feet. Figure 1, the print of a frame from the wide-angle camera, shows more of the western vortex. A certain part of this cloud system is due, no doubt, to the terrain. The vortex is not as well organized and the circular cloud arrangement less spectacular than in the primary system.

The primary system produced the abnormal rain, but areas of increased precipitation associated with the other two vortices can also be detected. Systems of this scale are very common in the upper troposphere at low latitudes, but this particular family of three extended all the way to the surface, providing a mechanism for abnormally rapid transport of moisture into the upper troposphere. It is significant that these vortices were embedded in an upper flow that curved anticyclonically toward the north then easterly over Illinois and that on October 10 Chicago had record floods [2].

Despite the importance of these vortices they were sufficiently small to be overlooked in the routine contour analysis. This suggests that subtropical regions may have flood-producing rains from systems that are so small that they are filtered out by the coarse grid of the standard numerical weather prediction methods. It is interesting to notice that the primary and the eastern vortices were discernable from a *detailed analysis* of time-altitude cross sections (along with all the routine analysis aids)—the type of analysis used in every careful tropical analysis where the data are frequently more sparse than in the United States. The vortex west of El Paso, however, was suspected but not inserted in the analysis until its existence was confirmed by the photograph. It is also significant that the vortex was not recognized on the photograph until after it was suggested by the meteorological analysis. This situation then, presents systems which bracket the detection threshold of our data network: the two eastern vortices that were detected by a subjective streamline analysis and the western vortex which could not be analyzed with any confidence. Notice this is referred to as a threshold of *data* capability because it requires subjective streamline analysis. All three vortices are below the detection threshold of contour analysis.

Another interesting feature is that these vortices were cold-core systems and had a decided slope with altitude. Since the primary system was in the vicinity of Brownsville at 1500 GMT October 4 and near Del Rio a day later, there is sufficient evidence to deduce the fact that

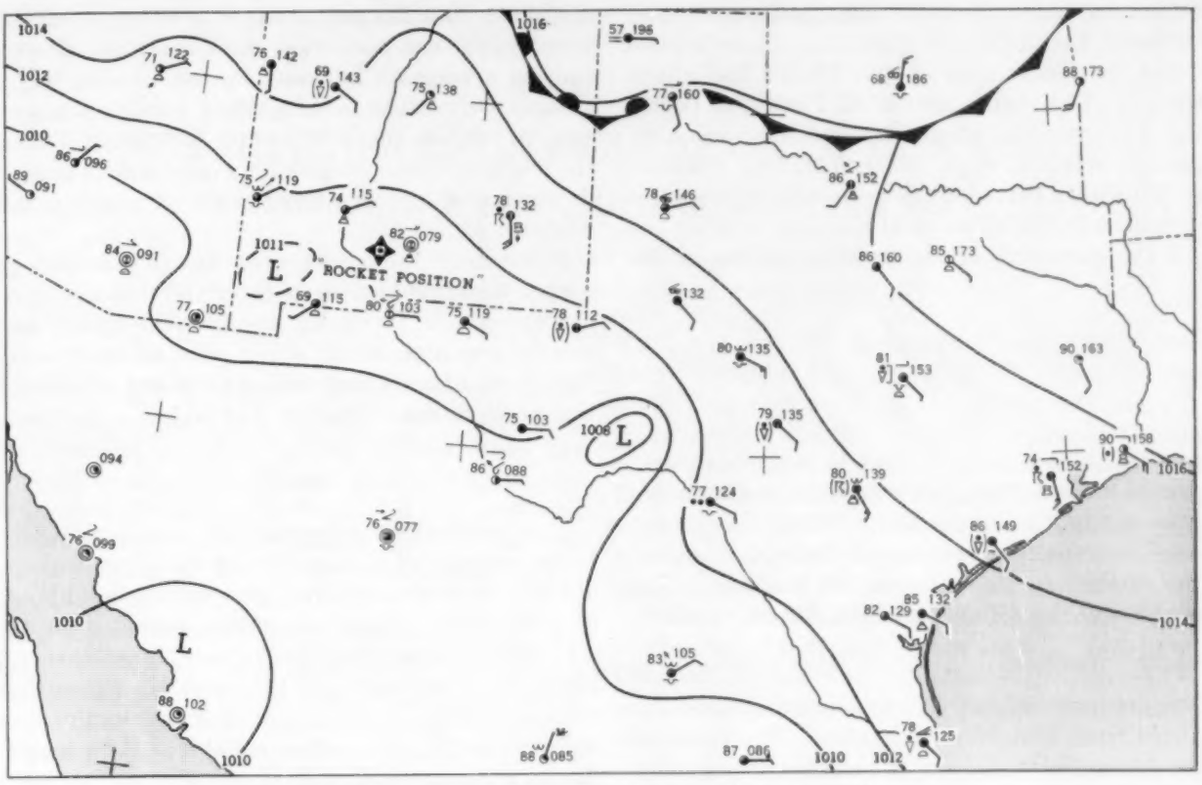

FIGURE 4.—Surface pressure analysis for 1830 GMT, October 5, 1954.

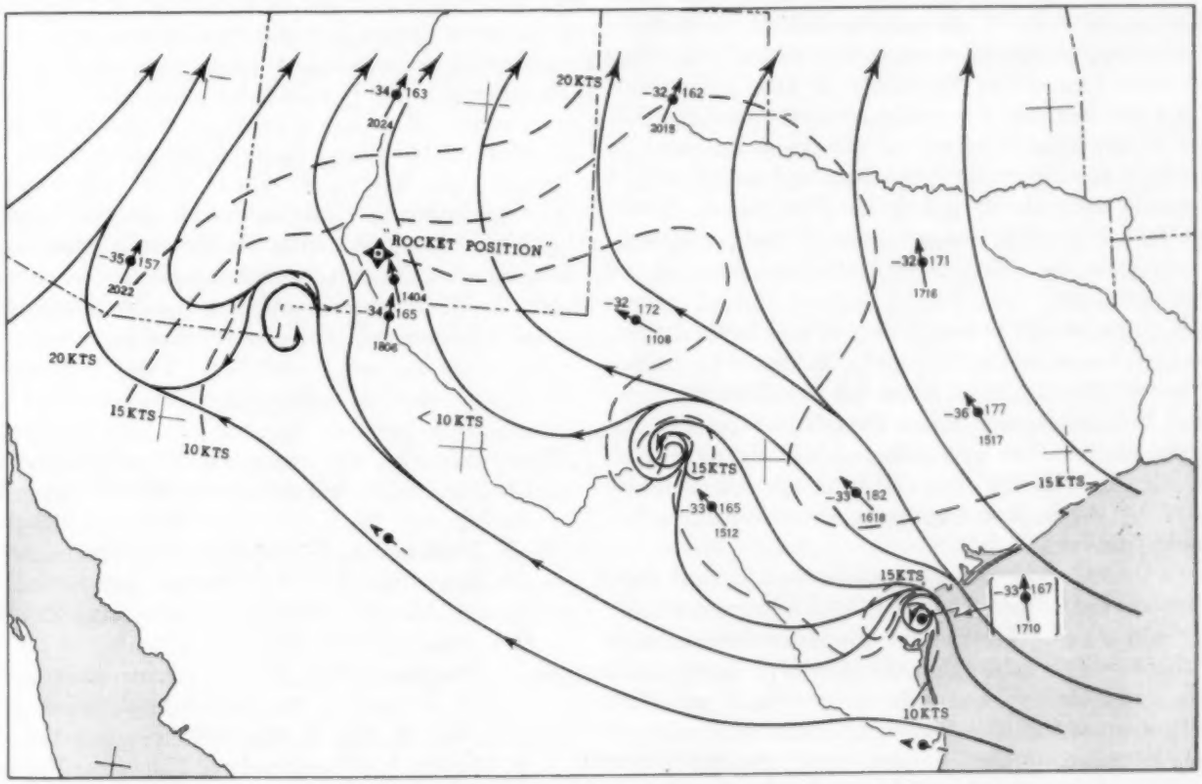

FIGURE 5.—Streamlines (solid lines) and isotachs (broken lines) of the 300-mb. surface for 1815 GMT October 5, 1954. The wind data have been interpolated for time of rocket flight and plotted at end of wind arrow in form "ddff". Height and temperature of the 300-mb. surface for 1500 GMT are plotted in conventional manner.

the vortex axis extended about 55 miles horizontally and 7 miles vertically, i. e., a slope of about 1:8. There is some evidence that the center near Corpus Christi had about the same slope. The vortex west of El Paso is so poorly documented however, that no slope estimate can be made.

An equation relating slope to temperature gradient (Panofsky [3]) shows that slope is a function of the temperature gradient in the layers of atmosphere bearing the vortex and the curvature of the pressure profile of the vortex:

$$\frac{dz}{dx}=-\frac{RT^2}{mgp}\frac{\frac{\partial^2 p}{\partial x^2}}{\frac{\partial T}{\partial x}}$$

Unfortunately data are not sufficient to make a reliable computation of the curvature, nevertheless it is interesting to make such a computation to determine whether or not the slope, deduced from meteorological analysis, is reasonable in view of the expected temperature gradient. The contour analyses of the 850-mb. and the 500-mb. surfaces were used to determine $\frac{\partial^2 p}{\partial x^2}$. With that value, the temperature gradient necessary to produce a slope of 1:8 was computed from Panofsky's equation. The result of 0.25° C. per 60 nautical miles agrees surprisingly well with the independent result obtained from a simple advection calculation. For the latter it was assumed that the isotherm pattern 100 miles upstream from the vortex was advected with the speed of the vortex (about 11 knots) and that the temperature increase at 700 mb. at Del Rio after the center passed was due solely to that advective effect. The result from this computation was approximately 0.2° C. per 60 nautical miles. The close agreement must be largely fortuitous since the data and analysis are not sufficiently accurate to justify such precision. The significant fact is that the slope deduced from meteorological analysis is consistent with a reasonable temperature gradient.

The axis slope of the primary vortex was toward the southwest with height on October 4 when it passed Brownsville and toward the southeast when it passed Del Rio one day later. From this, one infers that the isotherms of mean virtual temperature were oriented NW–SE over the Gulf of Mexico and NE–SW over Del Rio. Such a pattern is suggested by the isotherm analysis, but the pattern is not a simple one.

The facts that the systems were cold-core and that the primary system did not quite develop into a hurricane are intimately connected. Hurricanes are invariably warm-core and there is little doubt that the hurricane winds and the tremendous convergence into a hurricane at low levels depend upon the core becoming warm so that the energy of latent heat can be converted *directly* into circulation acceleration. Stated in another way, we might say that the only manner in which condensation of water vapor can accelerate the circulation directly is by causing a pressure fall near the center and this in turn obtains only when condensation produces a warm-core system. When the level of non-divergence is situated in the middle or upper troposphere (as it is with most tropical disturbances) the organized zones of convection remain cold-core [4].

Apparently there was convergence into the primary vortex throughout a deep layer (level of non-divergence perhaps above 300 mb.) so that the entire ascending column was maintained cooler than its environment and the released latent heat was not utilized in direct circulation acceleration. (See fig. 1 of [4].)

4. CONCLUSIONS

The possibilities suggested by this accidental rocket reconnaissance of a tropical storm are tremendous. One obvious use is already being planned—rocket photography of hurricanes. There are many unsolved problems in meteorology that may be vulnerable to this approach however. Vast regions of the earth are still meteorologically unexplored territory. For example the important meteorological zone across equatorial Africa and South America has been described in only the crudest detail. The fact that huge amounts of rain are precipitated along this zone makes it quite important to several problems. Rocket photography has the advantage of providing truly simultaneous data, albeit of a specialized nature. Rocket and aircraft reconnaissance then, may well supplement each other in a highly successful manner.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the helpful and stimulating discussion with Dr. Harry Wexler relative to the meteorological aspects of this paper. The cooperation of Mr. J. W. Townsend and Dr. Les Meredith of Naval Research Laboratory was also invaluable.

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THE WEATHER AND CIRCULATION OF JUNE 1955[1]

ILLUSTRATING A CIRCUMPOLAR BLOCKING WAVE

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1. INTRODUCTION

During the first 6 months of 1955 the hemispheric weather pattern was seldom entirely free of blocking activity. This was particularly true of June, when the blocking could easily be associated with the unusually cool weather over the United States. This was a reversal from the general temperature regime of May [1] and was accompanied by one of the lowest zonal index values (5-day mean) ever recorded.

It is the purpose of this article to examine in turn: the outstanding monthly circulation characteristics including the half-monthly features and changes, the United States weather in light of the above, and a week-by-week evaluation of a pronounced blocking surge as revealed by 5-day mean maps and anomalies at 700 mb. This blocking surge was somewhat unusual in that one could trace its effects about the Pole for almost two complete revolutions.

2. MONTHLY AND HALF-MONTHLY CIRCULATION FEATURES

Indications of blocking activity are quite evident on the mean 700-mb. map for June, figure 1. In the Atlantic the westerlies were well south of normal with weakly above-normal heights over Iceland. These were connected by way of Davis Strait to the maximum anomaly of the month, a positive departure of 310 ft. over eastern Hudson Bay. This appears to have been the mean locus of blocking activity. In the middle-latitude trough along the east coast of the United States heights were below normal in the usual sense of high-low latitude compensation. Enhanced cyclonic activity, depression of westerlies, and colder-than-normal temperature regime south and east of the blocking center were also typical of the usually expected relationships.

Over North America the westerly flow was much weaker than normal except at very low and high latitudes—a feature closely associated with the split jet streams which are common to some definitions of blocking. And, a split jet was quite evident on the mean maps at higher levels (Charts XIV and XV).

Circulation changes over the Pacific have been relatively small the last few months. Heights have maintained above normal in a nearly zonal band which has been about parallel to and north of the subtropical ridge axis. In consequence, Pacific winds have been stronger than normal at latitudes north of the axis of positive anomaly. In June this northward displacement was most marked in the eastern Pacific, while the intensification of 700-mb. westerlies was about the same in eastern and western sections (up to 7 m/sec. greater than normal).

The Aleutian Low was at about normal intensity, and the western Pacific and eastern Asiatic troughs were near their normal locations. At sea level (Chart XI) one also could see the enhancement and northward shift of the westerlies in the eastern Pacific.

Blocking traces were again evident in Asia where heights were 240 ft. above normal and sea level pressures 4 mb. above normal in the anticyclone northeast of the Caspian Sea. Over Europe and the Norwegian Sea heights were not far above normal but at sea level a ridge of high pressure stretched from northern Greenland to the Mediterranean.

The 15-day 700-mb. means for the first and last halves of June afford further insight into the general trend of events. During June 1-15, (fig. 2A) blocking was most prevalent and intense from the Norwegian Sea westward through central Canada (heights +360 ft.). The westerlies were far south of normal and a zonal band of below normal heights reached from eastern Europe to the Central Plains of the United States. This continued depression of the westerlies appeared to be an extension of the trend begun during the latter half of May [1] when similar but less marked characteristics were present. Such tendencies are strongly opposed by the northward seasonal trend of the westerlies.

Short wave spacing, truncated troughs, cut-off Lows, and warm higher-latitude Highs characterized the area from central Europe through North America. Asia and the Pacific appeared less affected. Indeed the polar westerlies were exceptionally strong over most of Asia—a direct reversal from the latter half of May [1].

During the latter half of June (fig. 2B) blocking relaxed over the Atlantic and Europe. While blocking continued over North America (heights 260 ft. above normal over Hudson Bay) heights rose at lower latitudes and many of

[1] See Charts I–XV following p. 137 for analyzed climatological data for the month.

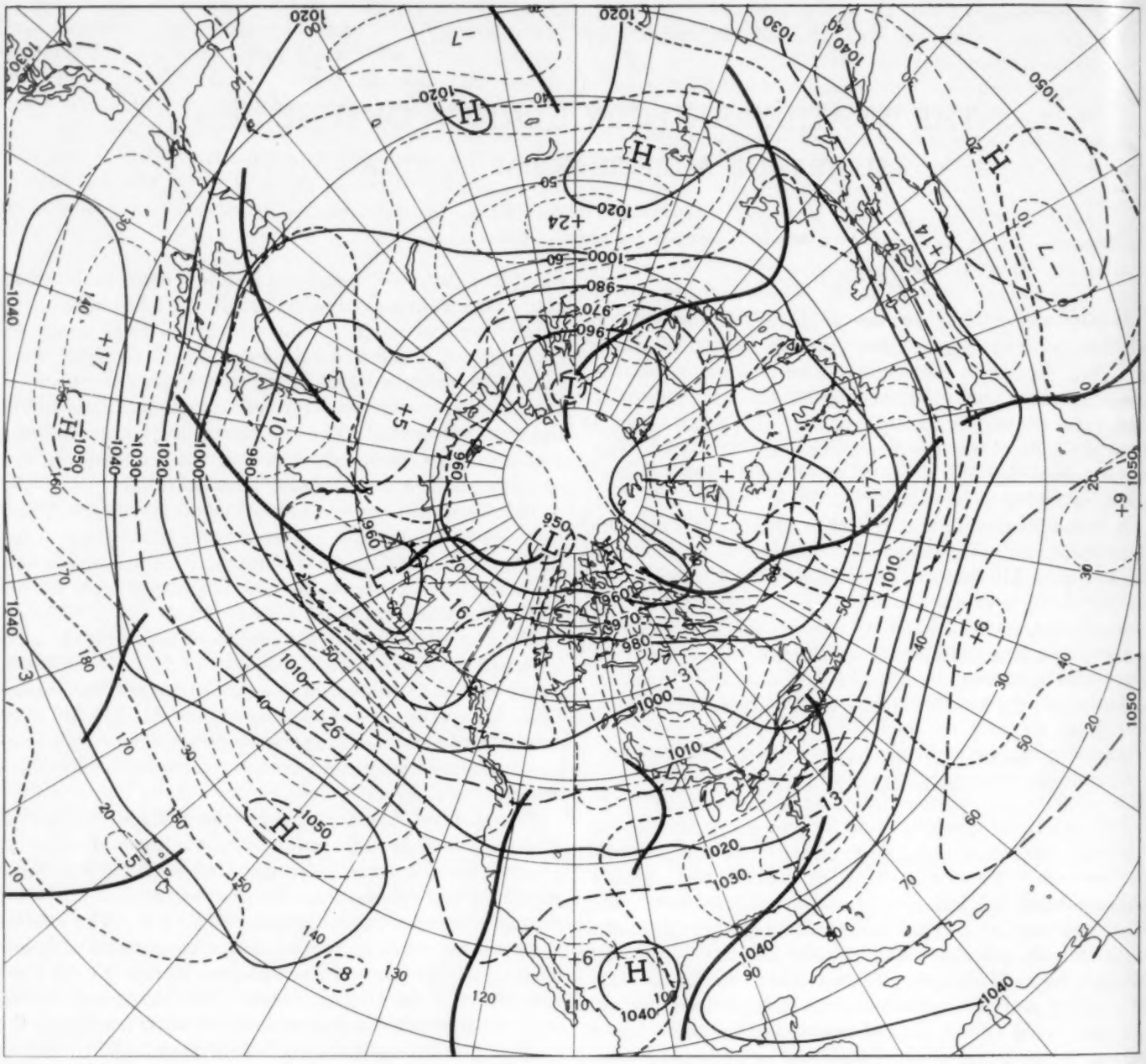

FIGURE 1.—Mean 700-mb. contours and height departures from normal (both in tens of feet) for May 31–June 29, 1955. Effects of blocking are apparent in the depressed Atlantic westerlies, are most marked over North America (heights 310 ft. above normal over Hudson Bay and 130 ft. below normal off Cape Hatteras), inconspicuous in the Pacific, but again observable in the positive anomaly stretching east-northeastward from the Caspian Sea.

the concomitants of strong blocks weakened or disappeared. However, quite strong blocking activity was centered in eastern Asia where split jet, cut-off Low, and warm High were present.

Thus, blocking dominated the European, Atlantic, and North American sectors during the first half-month, never entirely inverted the Pacific circulation, but strongly influenced Asia during the second half-month.

3. UNITED STATES WEATHER AND ANOMALIES

The below normal temperatures of June were the most noteworthy feature of the weather this month. Temperatures averaged 4° F. or more below normal in a wide belt from North Carolina to the Central Plains (Chart 1-B). In parts of the northern border States from North Dakota to New England temperatures were above normal, as they

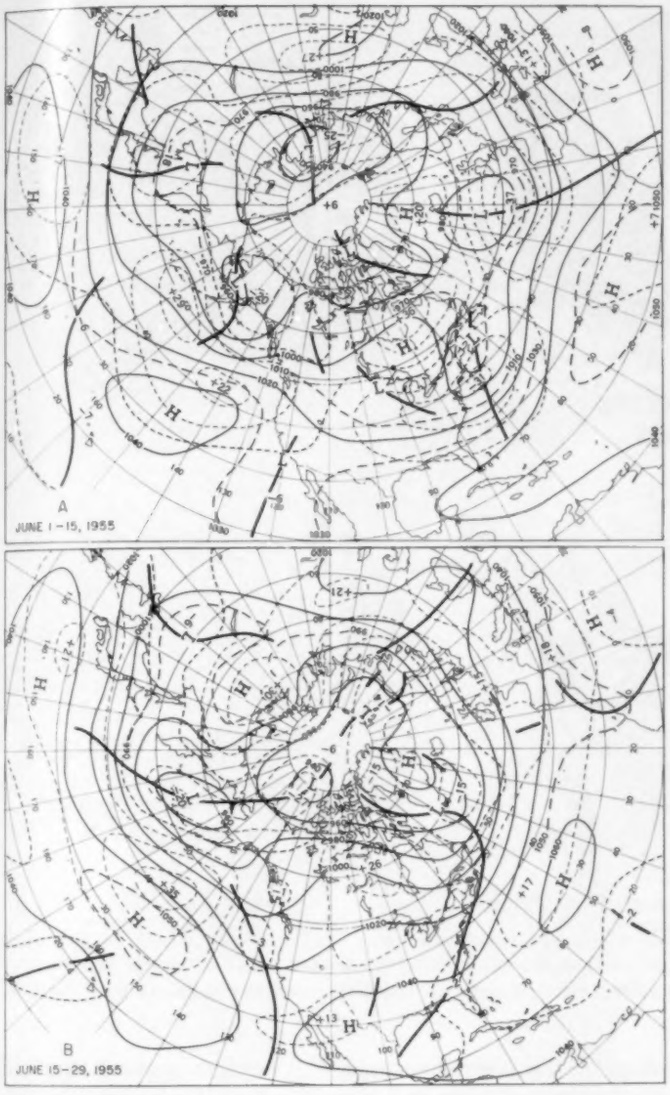

FIGURE 2.—Mean 700-mb. contours and height departures from normal (both in tens of feet). (A) June 1–15, 1955. Blocking strongly affected the area from the Norwegian Sea through central Canada. Twin cyclonic vortices at middle latitudes show the westerly reaction to Atlantic blocking. Truncated troughs and poorly defined flow pattern characterized western North America. Cold air from Canada, and cyclonic activity kept the eastern two-thirds of the United States unseasonably cool. (B) June 15–29, 1955. Blocking was still operative over North America but considerable recovery was evident over Atlantic sections as the westerlies worked northward. Blocking was most strongly marked over Asia where heights were 300 ft. above normal in the anticyclone northeast of Lake Baikal.

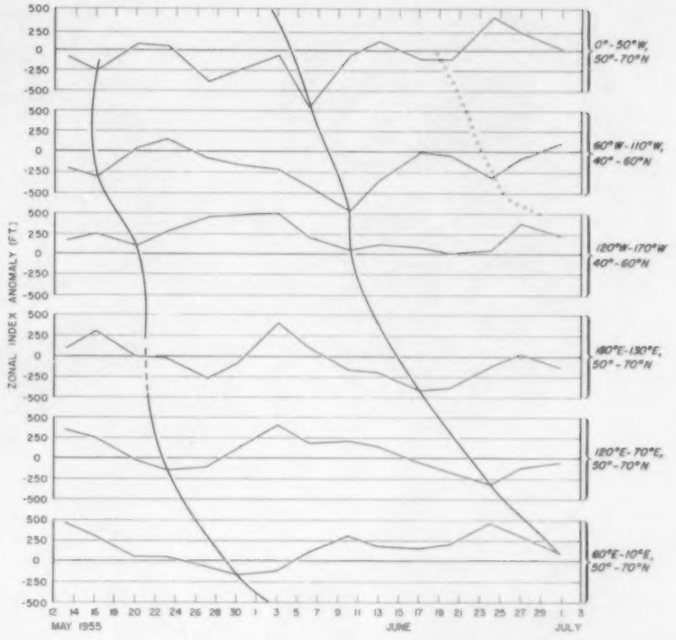

FIGURE 3.—Five-day mean circumpolar zonal index anomalies at 700 mb. by 60° longitude bands for indicated latitudes. (Note, an anomaly of +500 ft. represents about 6.1 m/sec. anomalous westerly flow for 40°–60° N., and 5.4 m/sec. for 50°–70° N.) Mean values are plotted at mid-date of period. Sloping lines show progressive upstream diminution of westerlies, usually to below normal values, and trace retrogression of blocking surge. Dots show secondary abortive block of late June.

were also in the upper Columbia and Snake River Valleys and along the Rio Grande. All other areas recorded below normal temperatures.

Extremely cool conditions were noted the first half-month when the blocking was most intense over Canada, and slow-moving cyclonic developments over the central United States were followed by cool Canadian air. The cloudiness attendant on the cyclones depressed maximum temperatures and the Highs which swept down in their rear kept temperatures below normal. In the Central Plains temperatures averaged 10°-12° F. below normal the week ending June 12. During the 5-day period June 8–12 the zonal westerlies (0°–180° W. and 35°–55° N.) dropped to a value of 3.2 m/sec., the lowest zonal index of record in June (last lower value of record: 3.1 m/sec. for May 4–8, 1946). During the following week, extreme conditions moderated somewhat but temperatures still averaged some 8°–9° F. below normal over the southern Appalachians.

In contrast to the marked cold weather in the East, June 1–15 provided about the first extensive warm spell over the Far West since the beginning of the year. This could be associated with the disappearance of the west coast trough at middle latitudes as heights rose above normal and general anticyclonic conditions prevailed aloft. Also, the strongly divergent pattern over western North America permitted only very limited advection of cool maritime air from the Pacific, with the major migratory systems affecting western Canada rather than the United States. The highest temperature during this warm spell was 100° F. recorded at Seattle on June 9—an all-time June maximum for that station.

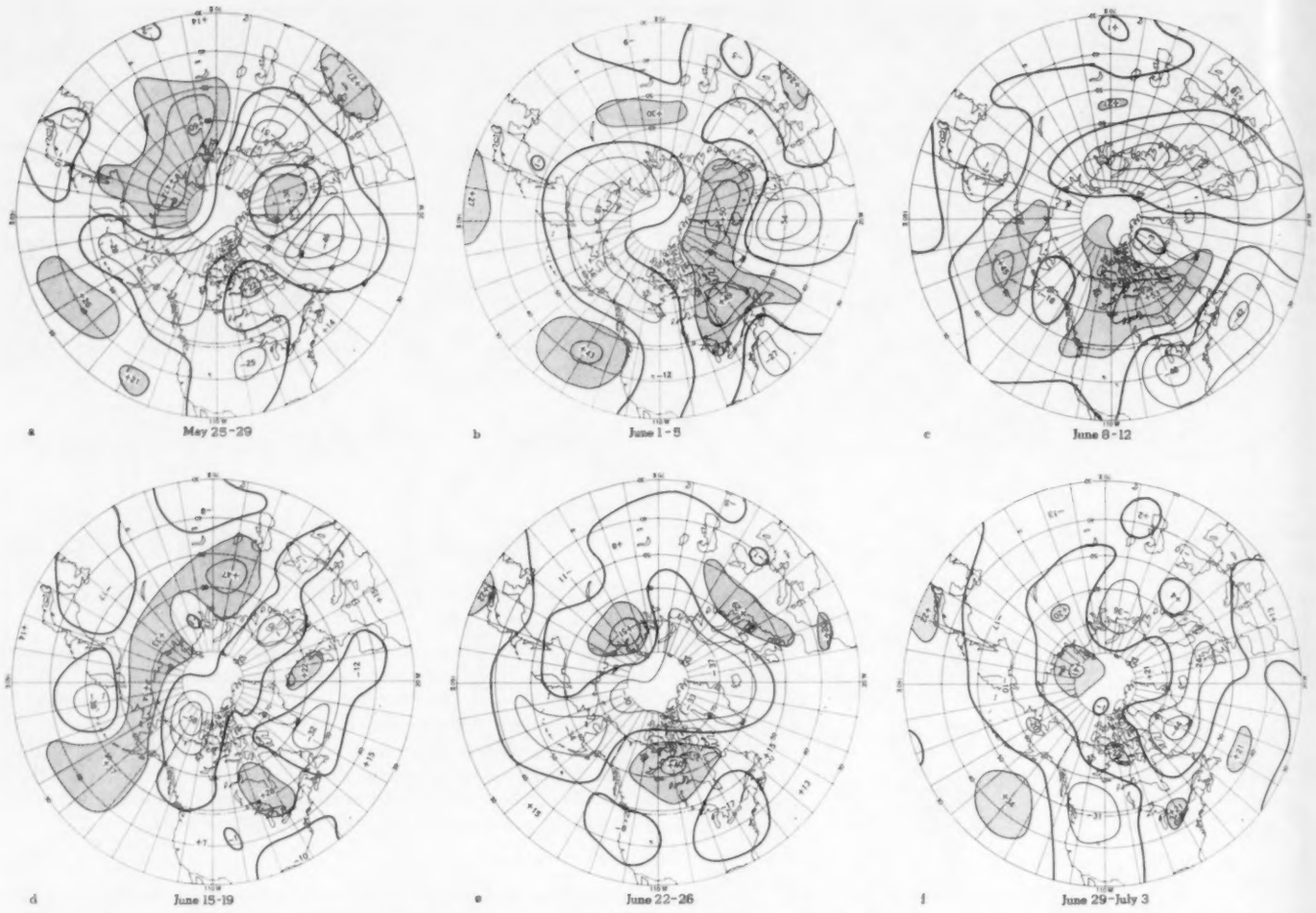

FIGURE 4.—Series of 5-day mean 700-mb. height departures from normal (in tens of feet). Isopleths are for 200-ft. intervals with positive anomalies greater than 200 ft. shaded. Note spread of positive anomalies from Asia westward until they appear to spiral in to the Pole.

Other early June weather items included a dust storm with winds of 55 m. p. h. at San Angelo, Tex. on the 8th, cloudbursts and flash floods in Nevada on the 13th, and scattered tornado activity.

During the second half of June there were two features of principal interest. One was the reactivation of the west coast trough with stronger than normal maritime flow affecting the West. This restored below normal temperatures over the Far West where they have been prevalent most of the year. The second was the persistent, although weakened, block centered over Hudson Bay which continued to effect below normal temperatures from the Central Plains eastward through the Carolinas. The departures were less than in early June but the general pattern of anomaly (east of the Rockies) was strikingly similar.

This persistent temperature pattern over the eastern two-thirds of the United States was part of the strong reversal in temperatures which took place between May and June. In the West, the two contrasting half-months produced a considerable net change from the May anomalies. As a consequence, this year has been unusual in its departures from the recent course of month-to-month persistence [2].

From April to May 1955 [1] persistence was exceptionally marked (98 percent of stations in 0+1 class change), whereas in recent years April-May comparisons have shown a preponderance of temperature reversals. The same records show on the average about 70 percent persistence (0+1 class change) from May to June. This year only 35 percent persistence—about one-half the average—was noted. These deviations from the recent monthly sequences are all the more interesting in light of the extension of these data to some 60 years of record by Enger [3]. His data show low April-May but quite high May-June temperature persistence. In this light also, 1955 has been quite anomalous.

The prevalence of blocking with its diversion of storms to the south was conducive to fairly widespread precipitation over the United States. In contrast to the early summer droughts of recent years there was nearly adequate precipitation during June over almost all of the

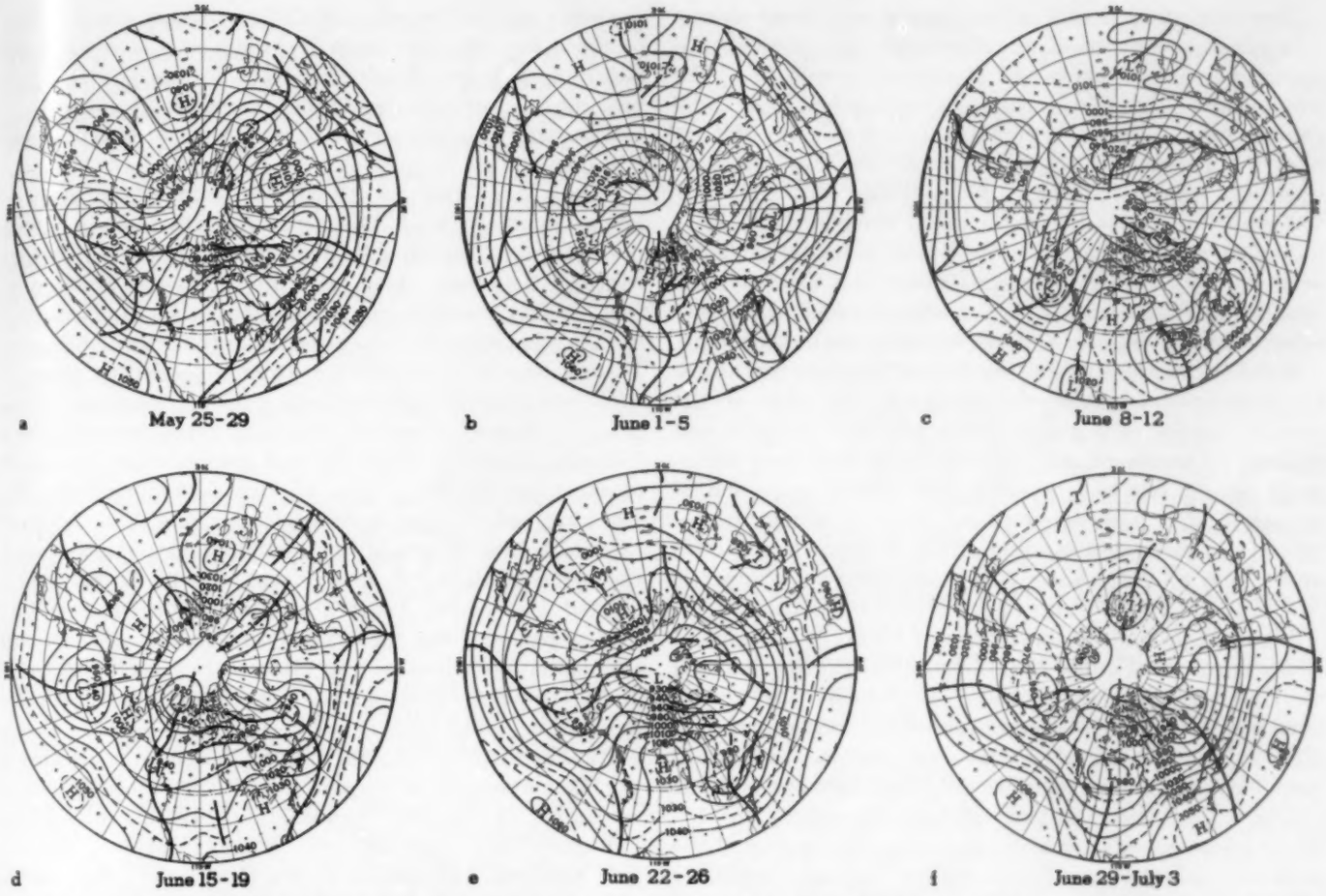

FIGURE 5.—Series of 700-mb. 5-day mean maps corresponding to dates of figure 4. Heights are in tens of feet. The retrogression of blocking across the Atlantic in early June is easily discernible and its effects on lower latitudes may be regarded as almost classic. Pacific reaction to blocking was less marked (c and d) although Asiatic response was quite strong (e).

United States. Although reserves of ground moisture were fairly low in some areas, crops were generally in excellent condition and a near-record yield seemed likely.

Severe weather was reported in numerous localities but most noteworthy was the 10 to 20 inches of rain which fell over part of southeastern Wyoming. This occurred in connection with a rash of tornadoes and hailstorms which also affected Nebraska June 26–27. These brought the threat of flooding to the placid North Platte River for the first time in many years.

4. A CIRCUMPOLAR BLOCKING SURGE

The overall prominence of blocking activity this June was sufficient to evoke general comment. As indicated previously, it had no uncertain role in the cool June temperatures over the United States and, judging from newspaper accounts, it could be associated with drought and forest fires in south central Canada.

The outstanding characteristics of blocking have been long recognized, e. g., Garriott [4], Namias [5], and its synoptic and climatological features delineated, e. g., Elliott and Smith [6], Rex [7], Sanders [8], and Sumner [9]. However, there has been only a slow growth in emphasis upon the retrogressive phenomena commonly called blocking surges, blocking waves, blocking action, etc.

Most meteorologists who have studied hemispheric weather changes for any considerable period of time have agreed that following the initiation of a block one can often, but not invariably, trace changes in the circulation which occur progressively upstream. Garriott mentioned the slowing down of migratory systems over North America following stagnation and anticyclogenesis in the Atlantic and Europe. Willett found small but positive one-week lag correlations (zonal index) between the Atlantic and North America [10]; Namias [2] illustrated this effect by showing the progressive upstream diminution in the 10,000-foot zonal index and the accompanying accretion of mass of air above 10,000 feet for 2 cases in early 1944. Berggren, Bolin, and Rossby [11] demonstrated similar retrogressive phenomena on daily charts. Early theoretical models by Rossby [12, 13] and Yeh [14] were proposed to account for these phenomena.

However, there is also rather general agreement among synopticians that blocking effects are propagated upstream in various forms and at various speeds, i. e., the whole warm High may retrograde—either bodily or "discontinuously", the next upstream trough may fill at higher latitudes and deepen at lower latitudes, the next upstream ridge may project meridionally into high latitudes and/or in turn become a warm blocking High, or it may join at least partially the initial blocking High by arching over the intervening trough, or heights may simply rise (upstream) at higher latitudes and fall farther south without singular 700-mb. circulations being set up.

Neither the exact timing nor type of reaction can as yet be predetermined from the pre-state. In view of the various modes of activity and variations in time and latitude of reactions, it is not surprising that rigid statistical testing has not revealed any unique sequence of events [6, 7]. This series of articles has, where appropriate, reviewed outstanding cases of blocking [15, 16] and tried to emphasize their retrogressive character. May-June of 1955 affords another such opportunity.

Figure 3 presents the evidence of blocking in terms of 5-day mean zonal index variations (about the local normal at 700 mb.) similar to those of Namias [2]. These sectional indices (60° longitude wide) encompass the globe. The 20° latitude bands used (indicated on fig. 3) have been chosen to maximize the blocking wave of June.

The block is shown initially affecting areas from 0°–110° W. in mid-May, after which progressive diminution of the sectional indices, usually to below normal (negative) values, occurred. The "minimum" 180°–130° E. around May 21 was not well marked and could be better demonstrated at lower latitudes, but only at the expense of the June surge. The retrogression of blocking action slowed down over Asiatic-European sectors during late May [1] but travelled rapidly across the Atlantic-North American sectors in early June. Some retardation was also evident in late June, again over the Asiatic-European sectors. In all but one section (eastern Pacific) the line denoting the second passage of the blocking surge passes through the minimum of the index values for the month. A minor secondary surge which affected the Atlantic-North American sectors in late June has been denoted by dots. One may observe that westerlies (40°–60° N.) were seldom above normal for the entire period between 60° W. and 110° W. In contrast the westerlies in the sector immediately upstream (120° W.–170° W.) were never below normal due to the persistent strength and orientation of the eastern Pacific High.

Although the index graphs of figure 3 are completely objective once the areas are chosen, they suffer the obvious deficiency of portraying the phenomenon in a severely constrained and segmented fashion. A more comprehensive picture of developments may be gained by studying the fields of mean height departure from normal, mean height change, 700-mb. temperature anomaly, or the 700-mb. circulation pattern itself. Two of these aspects have been included in this report: the 5-day mean height departures from normal and the 700-mb. mean circulation patterns. Because of space limitations only the last complete revolution of the blocking is shown.

Figure 4a, May 25–29, shows tremendous positive height anomaly over Asia, with heights already above normal from Greenland to Scandinavia as blocking began to affect that area. One week later (fig. 4b), above normal heights reached from Scandinavia to Hudson Bay with heights strongly below normal in the central Atlantic. During June 8–12 the block centered over North America with two intense lower-latitude cyclonic vortices. This was an almost classical blocking retrogression. (See following article by Robinson and Joseph where the effect of blocking on the motion of two Lows is discussed.) Blocking had also begun to affect the Pacific as the Gulf of Alaska Low filled and ridging extended northwestward through the Bering Sea. By June 15–19 blocking had relaxed over North America and the eastern Pacific. It now appeared from the central Pacific through Asia to the center northeast of the Caspian Sea. During June 22–26 the block failed to affect significantly the European circulation while heights were still some 510 ft. above normal in northern Siberia. In the period June 29–July 3 the block appeared to spiral in toward the Pole and further continuity of this type became difficult if not impossible.

Figures 5a–f show the corresponding 700-mb. circulation patterns. Figure 5a shows the Highs over central Asia and between Iceland and Norway. In 5b the western High has become dominant with a deep Low to its southwest and a weak Low to the southeast. The ridge over the United States was building and during the following half-week, June 4–8 (not shown) it connected across the Davis Strait with the retrogressive blocking center. In figure 5c the block was central over North America with closed vortices at lower latitudes; note however, ridging was already occurring in the Bering Sea. June 15–19 (fig. 5d), shows the block in the Pacific but only a rather weak anticyclonic arch from Alaska through northern Siberia. June 22–26 (fig. 5e) saw the remainder of the block over northern Asia, the secondary blocking surge centered over North America, and strong westerlies from the western Atlantic to western Russia. The last map (fig. 5f) shows a rather unusual arrangement of three anticyclones at high latitudes as the blocking seemed to be shunted northward while a fairly well-organized westerly regime operated to the south.

The recent prevalence of blocking and its intimate connection with higher-latitude pressure rises versus lower-latitude falls cannot but recall the somewhat similar responses associated with increasing solar activity by many researchers in this field. It may be pertinent to point out that this was a period of increasing sunspottedness. Mean Zürich spot numbers (provisional) for Janu-

ary through June 1955 read: 20.0, 20.8, 4.7, 11.3, 29.6, and 33.1. May and June were months of moderate spottedness following a pronounced minimum (the 11-year minimum occurred in 1954). The blocking activity in December 1943 through March 1944 illustrated by Namias took place at just about the minimum in the 11-year spot cycle, but slightly on the descending (long range) side. There has been no direct evidence produced here of any connection between sunspots and blocking, but the general similarity of their effects suggests a relationship which may have to be examined further if the theoretical models prove unable to satisfactorily anticipate blocking phenomena. The only evidence bearing on this subject which has yet come to light is presented in a recent article by Bolin [17] which seems to indicate that even a simple 72-hour barotropic forecast can catch the development of a warm higher-latitude High from an initial state characterized by well-marked wave amplitudes. Whether the initial buckling from a flat westerly flow can be equally well forecast is a question which has not yet been answered.

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THE EFFECT OF A BLOCKING HIGH ON TWO CONSECUTIVE LOWS OVER THE CENTRAL UNITED STATES, JUNE 7–11, 1955

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1. INTRODUCTION

During the first week of June 1955, ridge conditions dominated the eastern half of the United States. In the upper levels, this ridge moved into position from the west on June 1, a step in the westward progression of a blocking condition that moved onto the continent from the northwestern Atlantic Ocean. (See the preceding article by Hawkins.)

Surface cyclones associated with the deep upper trough immediately west of the ridge were diverted generally northward as they approached the Great Plains region. This is well illustrated by the cyclone tracks, Chart X.

At 500 mb., on June 6, a Low formed in eastern North Dakota in the trough that extended from Fort Smith, Northwest Territories through Huron, S. Dak. to central Texas. This Low moved southeastward along a slightly cyclonically curved path through the east coast ridge (fig. 1), and on June 11 became part of the major trough off the Atlantic Coast. On June 7 (fig. 2), the 500-mb. Low in western Canada showed signs of following in the path of the first Low and on June 8, entered the United States at approximately the 100th meridian. For the next 24 hours the path of the second Low almost coincided with that of the preceding one (fig. 1). At 1500 GMT, June 8, it was forecast by National Weather Analysis Center to be over St. Louis, Mo. in 36 hours, being expected to continue in the path of the first Low but at a somewhat slower rate. Instead, however, after 0300 GMT, June 9 (fig. 3), this Low turned abruptly southward and for 36 hours moved almost due south to a position southwest of Kansas City. Then the High over Hudson Bay weakened, as the blocking condition progressed westward, and the Low began to move eastward. In establishing the relationship between the two Lows and the westward movement of the blocking condition and its components, we shall attempt to account for the unexpected divergence of the path of the second Low from the one preceding it.

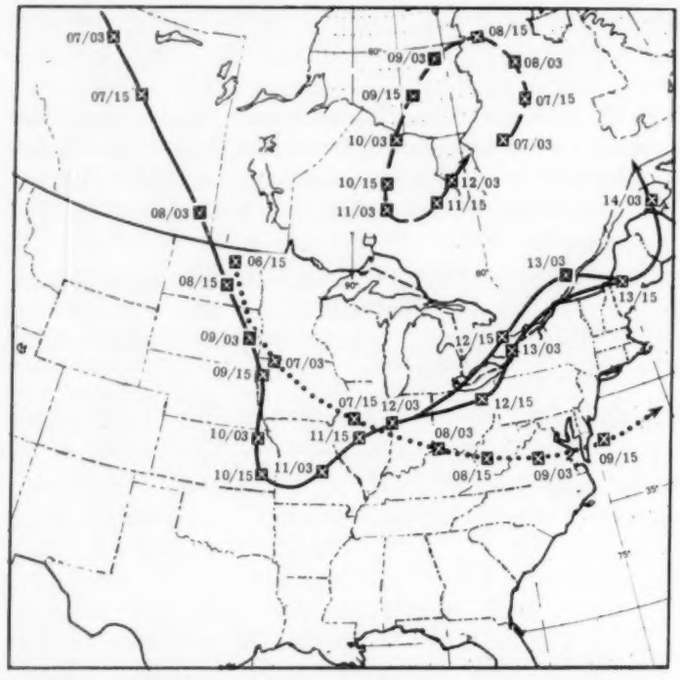


FIGURE 1.—Tracks of 500-mb. centers. Dotted line represents path of first Low; solid line, path of second Low; and dashed line is the path of blocking High. Crosses indicate 12-hour positions of centers.

2. DEPARTURE OF 1000–500-MB. THICKNESS FROM NORMAL

The 500-mb. height departure from normal and the 1000–500-mb. thickness departure from normal charts were investigated with respect to the circulation systems of June 7–11. The two series of charts showed essentially the same pattern, but the thickness departure from normal charts were selected for presentation here because they have the added advantage of presenting the temperatures throughout the area under study.

A comparison of the 1000–500-mb. thickness departure from normal charts of 0300 GMT for June 7 and 9, (figs. 4 and 5) demonstrates well the effect of temperatures in this layer on the movement of the two 500-mb. Lows as they entered the Midwest. At 0300 GMT, June 7 (fig. 4) there was a ridge of positive departures that extended north-south from just east of Hudson Bay to the southeastern States. The area of negative departures from normal centered over Omaha, Nebr. accompanied the cold air associated with the first Low. As this first Low approached the ridge over the Appalachians there was no

flow component directed against the cold air that would restrict its eastward movement.

Another action that cannot be ignored in considering the motion of the two Lows is the vortex-pair interaction. Two cyclones in close proximity to one another tend to rotate around each other in a counterclockwise direction. If the pressure field is otherwise flat the vortex-pair effect may be used in an almost objective fashion to determine the instantaneous direction of movement of the centers. As a flat pressure field is rarely the case in the middle latitudes, the relationship may be used only in a highly subjective but nevertheless useful manner. The vortex-pair motion of the two Lows considered here was such as to direct the first Low northeastward.

However, since a northeastward movement would have carried the Low into the opposing northeast flow from around the High, the resultant of these two actions was a movement slightly south of east. No sharp movement to the south could be expected since neither the packing of the 1000–500-mb. thickness departures from normal nor of the 500-mb. contours to the west of the Low indicated a flow component from the north strong enough to be generally associated with any appreciable southward movement. This first Low did move in essentially the direction forecast.

Forty-eight hours later when the second Low entered the Midwest the conditions were strikingly different (figs. 3 and 5). Whereas the first Low had encountered little or no opposing easterly flow components, the second Low met an easterly flow resulting from the progression of the first Low under the High. This flow imposed a much more southerly movement on the second Low. The 500-mb. winds reported at Pittsburgh, Pa., provide a good example of the contrast in flow regimes confronting the two Lows. At 0300 GMT, June 7, Pittsburgh reported a 500-mb. wind of 22 knots from 190°. The winds backed steadily and at 0300 GMT, June 9 were 29 knots from 50°. This was a change from a westerly component of 4 knots acting on the first Low to an easterly component of 22 knots opposing the second Low. Moreover, at 0300 GMT, June 9, the two Lows were significantly closer together and the tendency for vortex-pair interaction was appreciably stronger. This action tended to move the second Low in a path slightly west of south. Also, no negative departures from normal thickness followed the second Low that would tend to move it northeastward in the manner of the first one. The building of the upper level High over the Great Basin and the colder air at 500 mb. in the center of the second Low produced a departure from normal gradient to the west of the second Low almost double what it was when the first Low entered the Midwest. This greatly increased departure from normal gradient plus the more northerly flow to the west of the second Low forced the cold air associated with the Low to move almost due south. Thus, where the first Low was in a field that tended to give it an easterly path, the second Low was surrounded by conditions that individually, and certainly collectively, made mandatory a southward movement.

As the two 500-mb. Lows and the cool air associated with them entered and passed through the Midwest, the weekly average temperatures dropped from the above

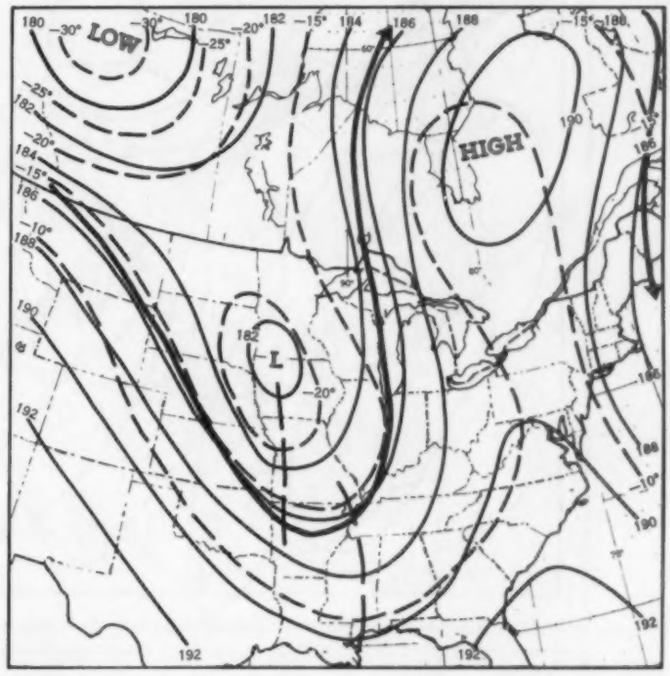


FIGURE 2.—500-mb. chart for 0300 GMT, June 7, 1955. Contours (solid lines) are in hundreds of geopotential feet, isotherms (dashed lines) in degrees Celsius. Heavy line is 300-mb. jet for same time.

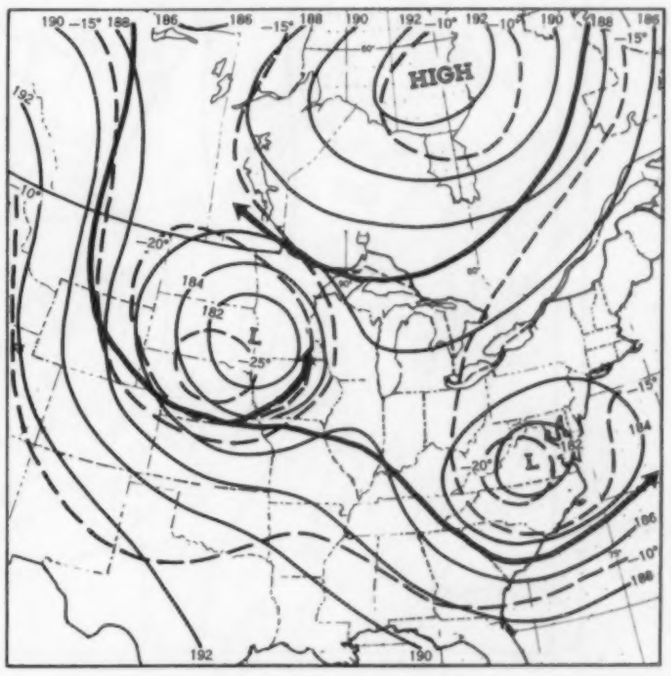


FIGURE 3.—500-mb. chart for 0300 GMT, June 9, 1955.

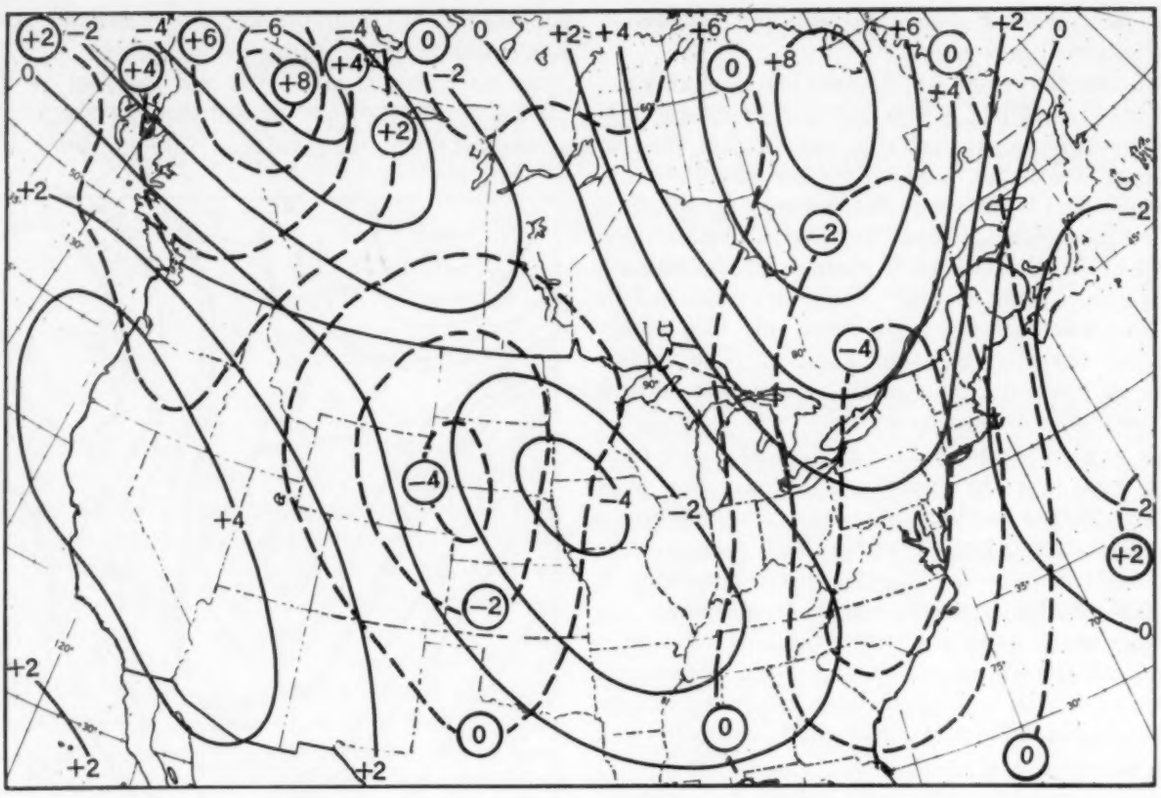


FIGURE 4.—1000–500-mb. thickness departure from normal chart for 0300 GMT, June 7, 1955. Solid lines are departures in hundreds of feet. Dashed lines show changes in hundreds of feet for the 48-hour period *following* this map.

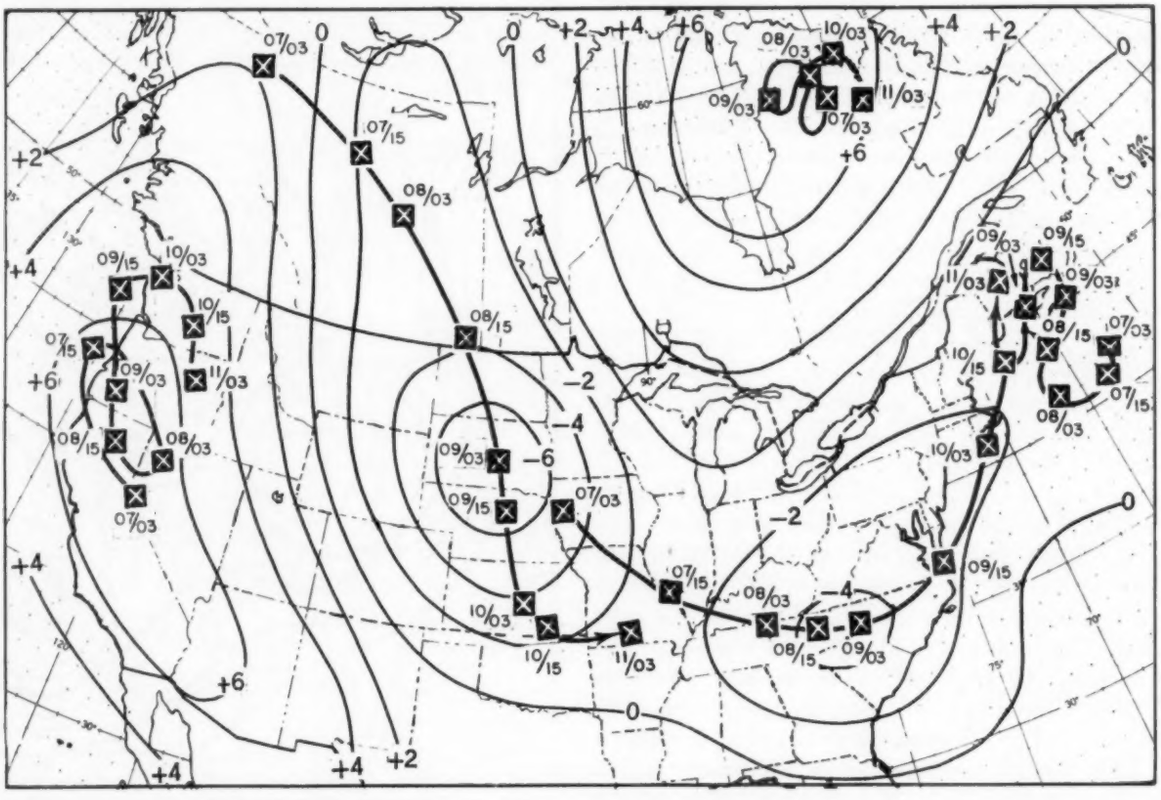


FIGURE 5.—1000–500-mb. thickness departure from normal chart for 0300 GMT, June 9, 1955. Crosses on tracks of anomaly centers denote 12-hour positions.

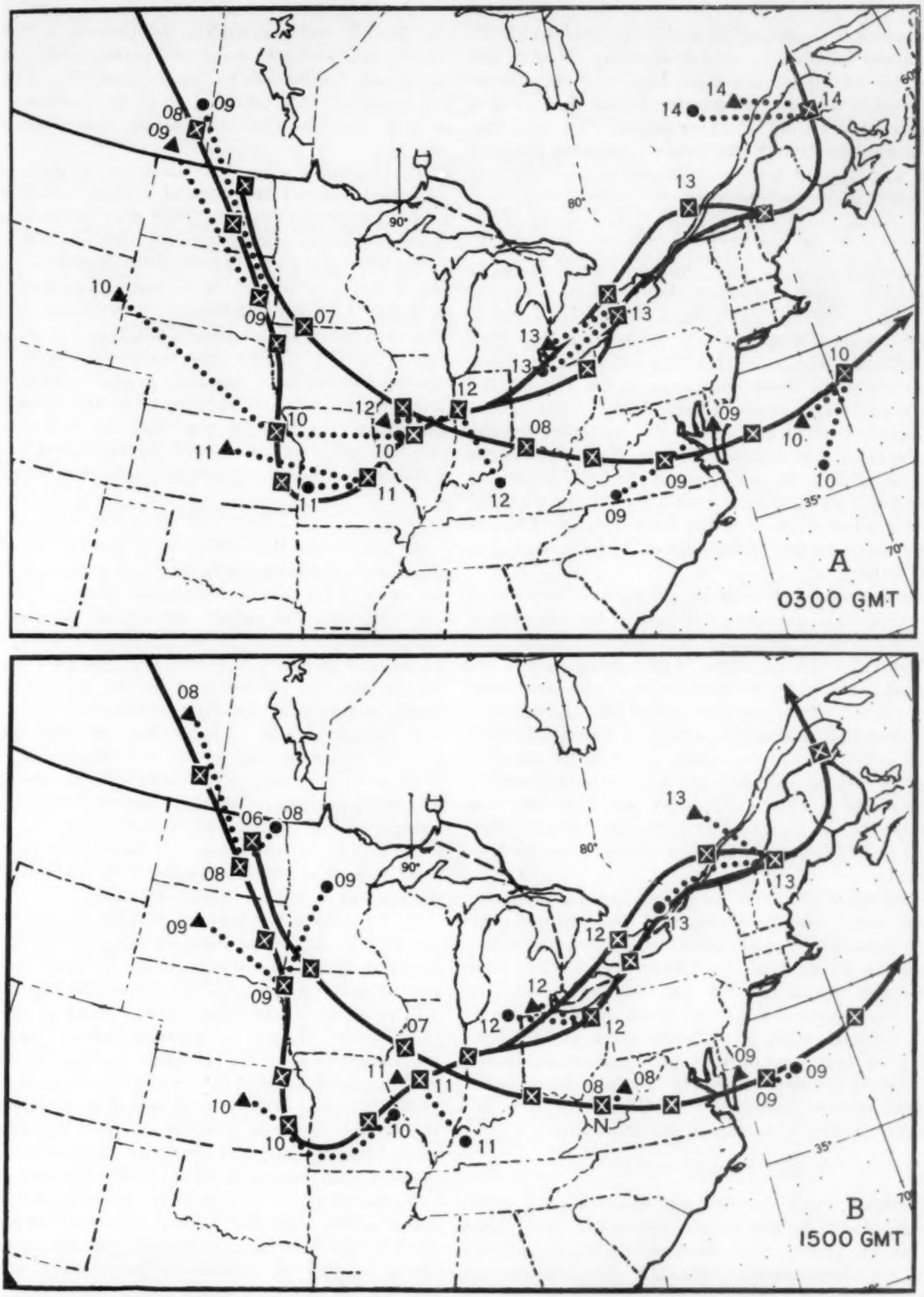


FIGURE 6.—Tracks (solid lines) of centers of two consecutive 500-mb. Lows labeled with day of month. Connected by dotted lines to the observed positions at verifying time are: in (A) the JNWP 36-hour 400-mb. prognosticated positions (triangles) and the NWAC 36-hour 500-mb. prognosticated positions (large dots); in (B) the JNWP 24-hour 400-mb. prognosticated positions and the NWAC 36-hour 500-mb. prognosticated positions.

normal values of the preceding week to as much as 12° F. below normal for the week ending June 13. West of the Continental Divide as the High built over the Great Basin, weekly average temperatures rose from below normal to as much as 12° F. above normal. The area east of the Mississippi River Valley received generous amounts of rain with several stations reporting more than two inches above normal for the week.

3. JETS AT 300 MB.

The movements of the two Lows were studied also in relation to the jets at the 300-mb. level. As the first Low moved into the Midwest the 300-mb. jet associated with it curved northward to its east over the Hudson Bay High then southward and under the Low off the east coast. This pattern prevailed until a trough opened between the first Low and a Low south of Sable Island. The picture then became that of one jet in the westerlies passing under the Lows that were south of the High and another jet circling all but the south quadrant of the High over Hudson Bay. By 0300 GMT, June 9 (fig. 3), the winds on the west-southwest octant of the High diminished to less than 50 knots with the leading edge of the jet extending to Lake Winnipeg.

A rule often used in forecasting the paths of upper level Lows is that their movement will parallel the direction of the maximum wind associated with them. As the first Low moved through the ridge, its path followed well the movement indicated by the single jet maximum associated with it. When the second Low moved into the Midwest (fig. 3), the wind field accompanying it was significantly different. The area of maximum winds in its southern quadrant would, by itself, indicate an eastward movement. But the combined effects of this jet and of the one that passed around the Hudson Bay High and through International Falls, Minn., resulted in a tendency for the Low to stagnate.

The 500-mb. charts, with the 300-mb. jets superimposed on them (figs. 2 and 3), display well the east-west components prevailing as the Lows approached the ridge. The 300-mb. jet south of the Hudson Bay High at 0300 GMT, June 9, was in an area that, relative to the Low centers, was essentially flat 48 hours before. This is another demonstration of the differences in the flows opposing the two Lows on their northeastern quadrants. These easterly components tended to retard the eastward movement of the second Low whereas they were not present at the time of passage of the first Low.

4. THE 500-MB. CHART

The 500-mb. chart for 0300 GMT, June 9 (fig. 3), shows a stronger northerly flow component west of the second Low than was present when the first Low was in approximately the same position (fig. 2). North-south and east-west component flow charts, constructed for this study (not shown) also demonstrate this. In addition the 500-mb. isotherm-contour relationship at 0300 GMT, June 9, indicated cold air advection that would contribute to 500-mb. height falls to the south of the center. The cross-gradient flow indicated on figure 3 was not present at 0300 GMT, June 7, as the first Low entered the Midwest (fig. 2).

The preceding discussion attempts to point out the dominant features that caused the second of the two Lows to move southward. They may be summarized as follows: (1) The northerly component was strengthened to the west of the second Low as the High over the Great Basin built northward with warm air pushing into Canada. (2) Cold air advection into the southern quadrant was indicated for the second Low but not for the first. (3) The easterly flow components were directed against the northeast quadrant of the second Low and were coupled with the appearance of the 300-mb. jet in the south quadrant of the High over Hudson Bay. (4) The vortex-pair motion of the two Lows was active as the second Low moved rapidly into the United States.

5. PROGNOSTIC CHARTS

As this is the first article of this series by National Weather Analysis Center dealing with a synoptic sequence for which the Joint Numerical Weather Prediction (JNWP) unit has issued operational forecasts, some mention of those forecasts may be in order. JNWP makes 12, 24, and 36-hour prognostics from the 1500 GMT charts for the 900-mb., 700-mb. and 400-mb. constant pressure levels, and vertical velocity prognostics for the 800-mb. and 550-mb. levels. The corners of their prognostic area are approximately 45° N., 165° W.; 45° N., 45° W.; 15½° N., 77° W.; and 15½° N., 133° W. As the numerical procedure assumes no vorticity advection and no height change at the boundaries, JNWP charts are trimmed about 5°, 10°, and 15° latitude on the east, north, and west sides respectively before delivery to NWAC to eliminate the areas of maximum "boundary effect."

Under June schedules, the NWAC analysts received the JNWP 24-hour prognostics about 20 to 30 minutes before making the thickness check between the surface and 500-mb. prognostics. After the thickness check the NWAC analysts had from 10 to 30 minutes to consider the JNWP 36-hour prognostics before tracing their prognostics to meet the facsimile deadline at 2006 EST. Due to machine failure on the evening of June 8, both the JNWP 24- and 36-hour prognostics were received after the NWAC facsimile deadline and it is the prognostics made from the 1500 GMT charts on June 8 that show the greatest disagreement between JNWP and NWAC.

Figure 6A shows the tracks of the two 500-mb. Lows under study and the JNWP (400-mb.) and NWAC (500-mb.) 36-hour prognostics verifying on the 0300 GMT charts. Figure 6B includes the two actual storm tracks, the NWAC 36-hour prognostics and the JNWP 24-hour prognostics that verify at 1500 GMT.

Weather Notes

STORM OF APRIL 21, 1955

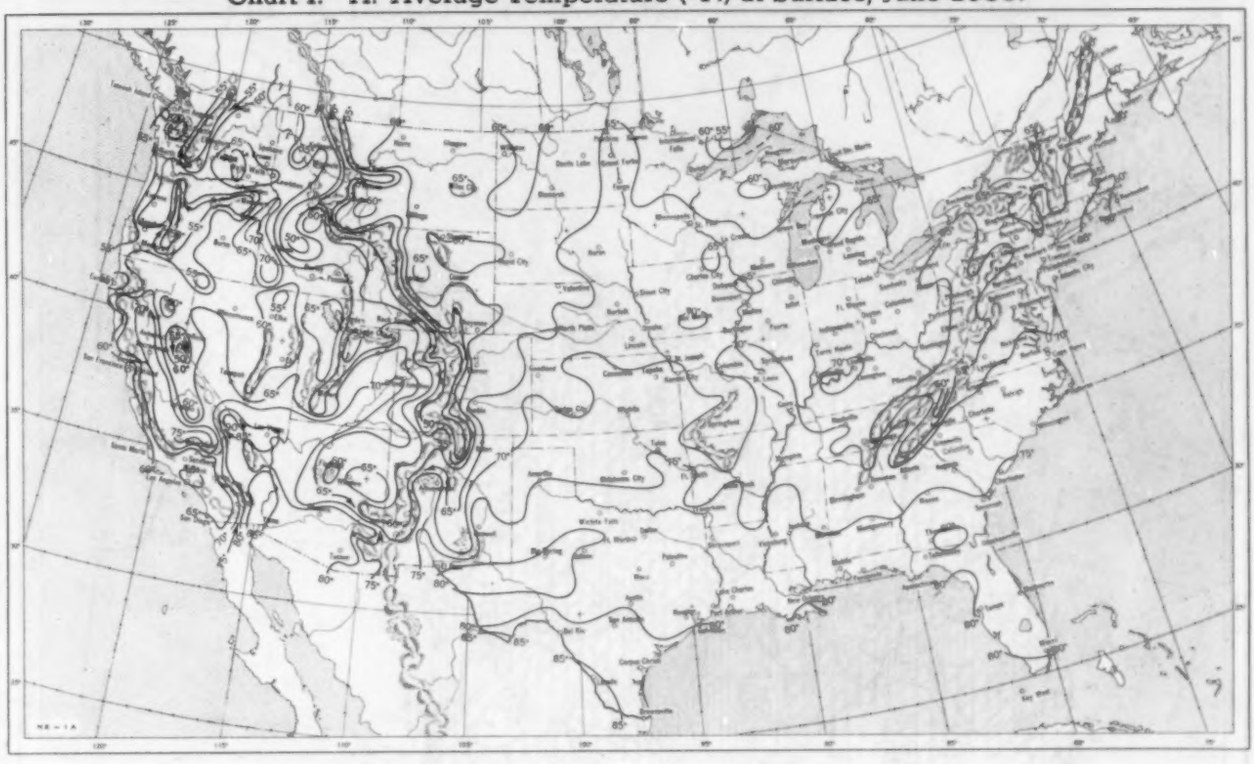
A violent storm, which may have been a tornado, struck the community of Leavell Woods, 3 miles south of Jackson, Miss., at 5:55 a. m. CST on April 21, 1955. It moved along a path about 100 yards wide from north-northwest to south-southeast. No funnel cloud was seen. The wind caused $500 damage; no casualties occurred. Rain, which was heaviest after passage of the most intense winds, lasted for 10 to 20 minutes and amounted to 0.14 inch. No hail was reported.

Three large pine trees about 80–100 ft. tall, bare of limbs for about 60 ft. from their bases, were toppled over toward the south-southeast. My neighbor, who was outside taking clothes from the line, saw the trees fall as she attempted to re-enter her home. The door slammed from the inside, locking her out, and she came to our home. She heard no noise from the falling trees although she was within 100 feet of them as they fell, due north of her location at the time. I was in my house within 150 feet of the falling trees. Although I could see the trees being bent at about a 45° angle to the southward, neither my wife nor I heard the attendant noise that usually accompanies the crash of trees of that size. I do recollect a slight jar which probably resulted when they struck the ground. These trees were well rooted, with large tap roots; wet ground probably contributed to their fall. The top was wrenched out of another tree 100 yards south-southeast of the fallen trees.

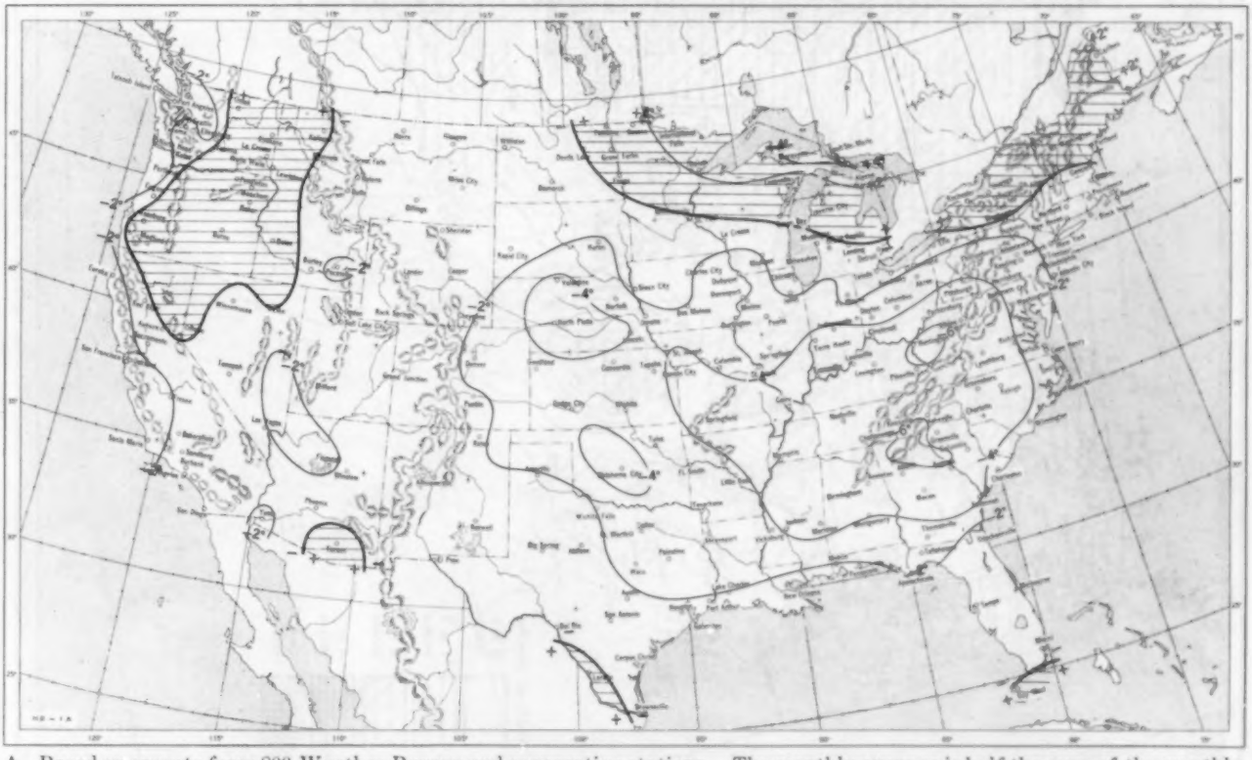
Neighbors distant ¼ to ½ mile on either side of the strongest winds reported hearing a steady roar, which would seem to indicate violent winds aloft. The only explanation that I could offer for the weird fact that suface winds of that strength and crashing trees produced no sound of the magnitude usually associated with such occasions may be inferred from Prof. Abdullah's article in the April 1955 issue of the *Monthly Weather Review*. I have had considerable experience with falling timber in and near logging operations; the crash of a large tree can ordinarily be heard for a considerable distance.

George V. Fish, WBAS, Jackson, Miss.

Chart I. A. Average Temperature (°F.) at Surface, June 1955.

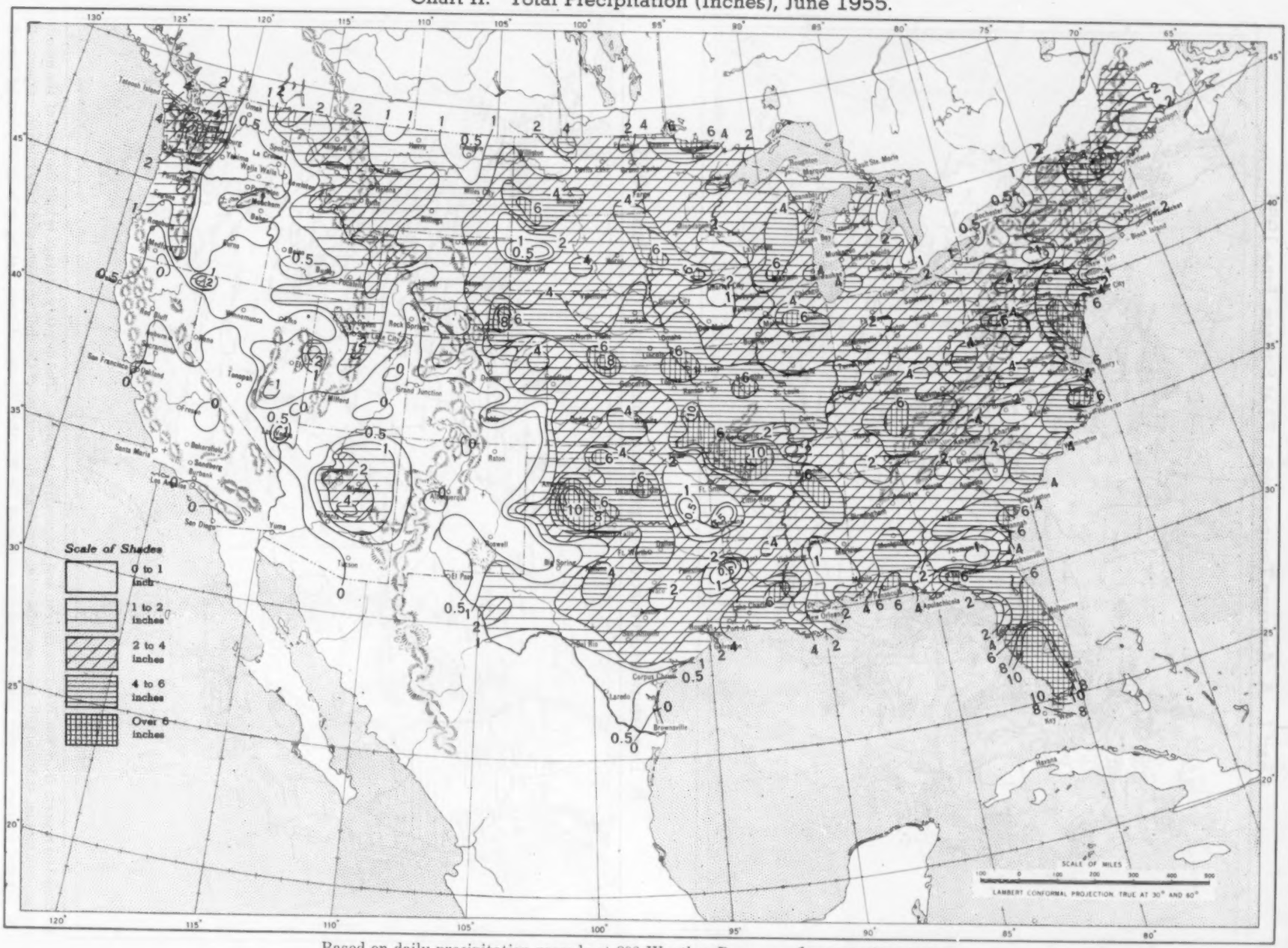


B. Departure of Average Temperature from Normal (°F.), June 1955.



A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

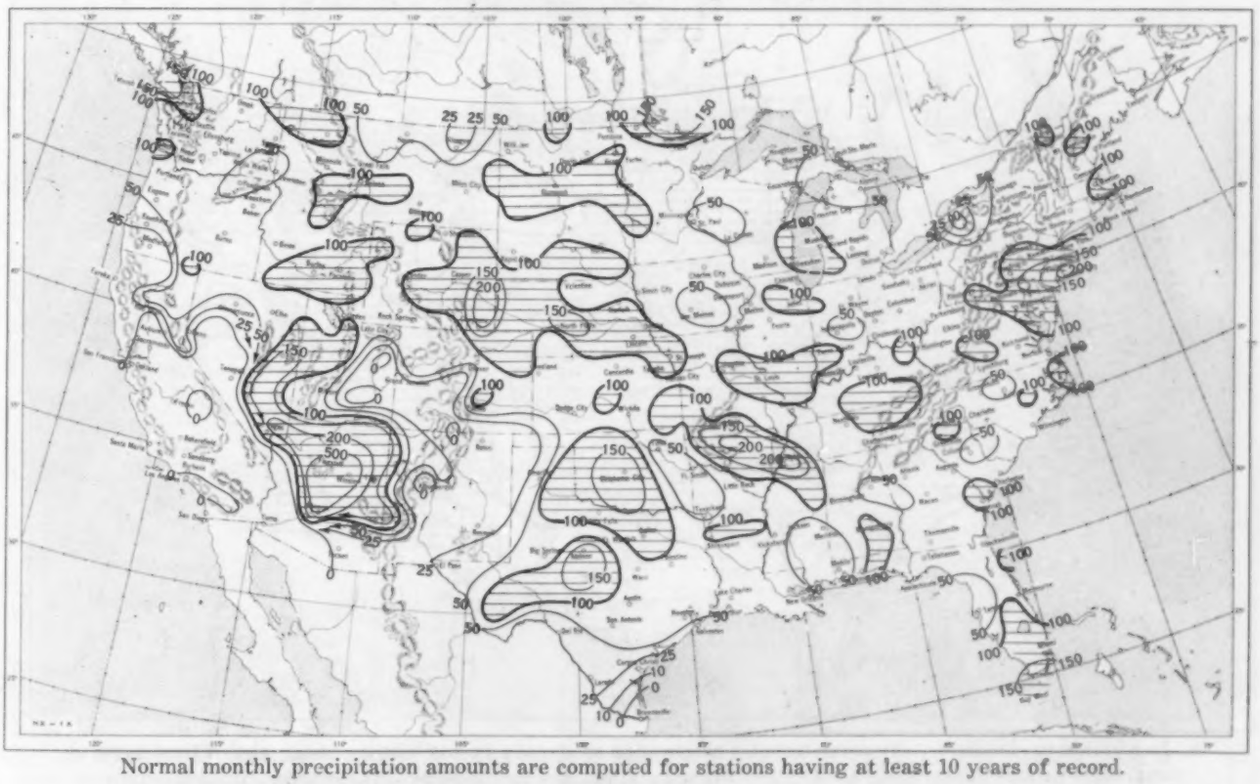
Chart II. Total Precipitation (Inches), June 1955.


Scale of Shades
0 to 1 inch
1 to 2 inches
2 to 4 inches
4 to 6 inches
Over 6 inches
SCALE OF MILES
LAMBERT CONFORMAL PROJECTION TRUE AT 30° AND 60°

Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

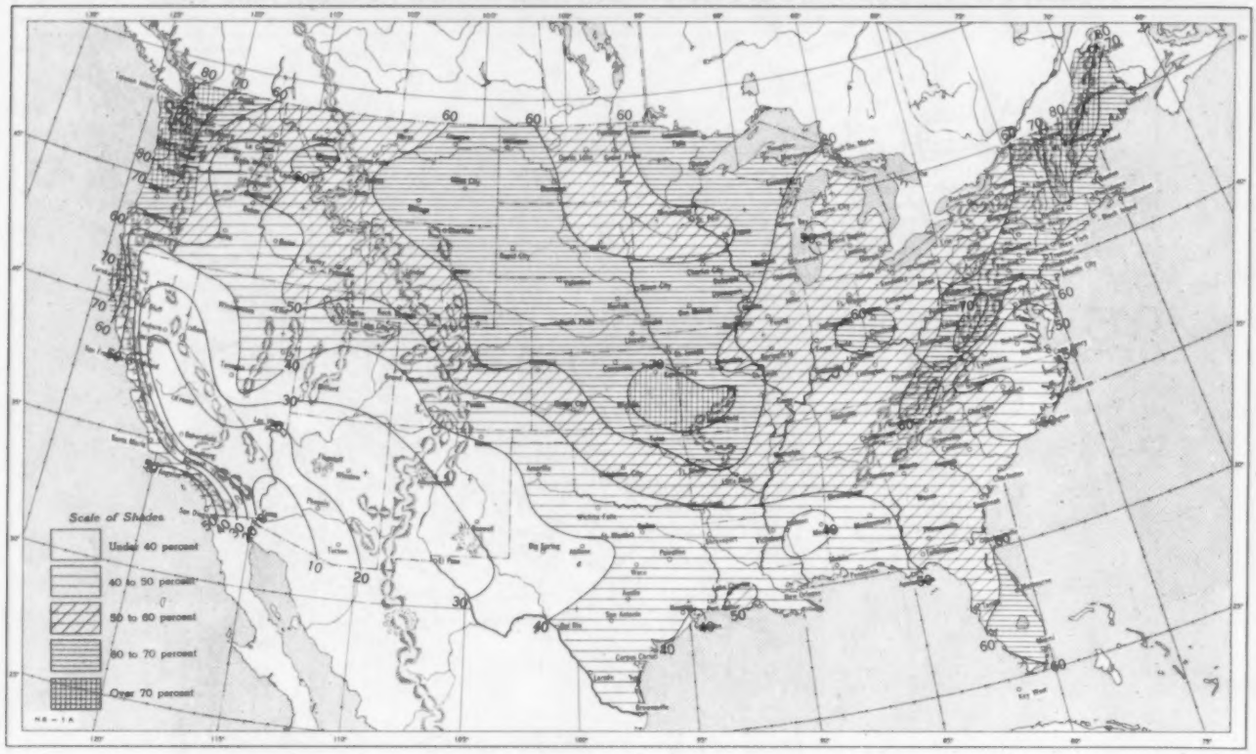
Chart III. A. Departure of Precipitation from Normal (Inches), June 1955.

B. Percentage of Normal Precipitation, June 1955.

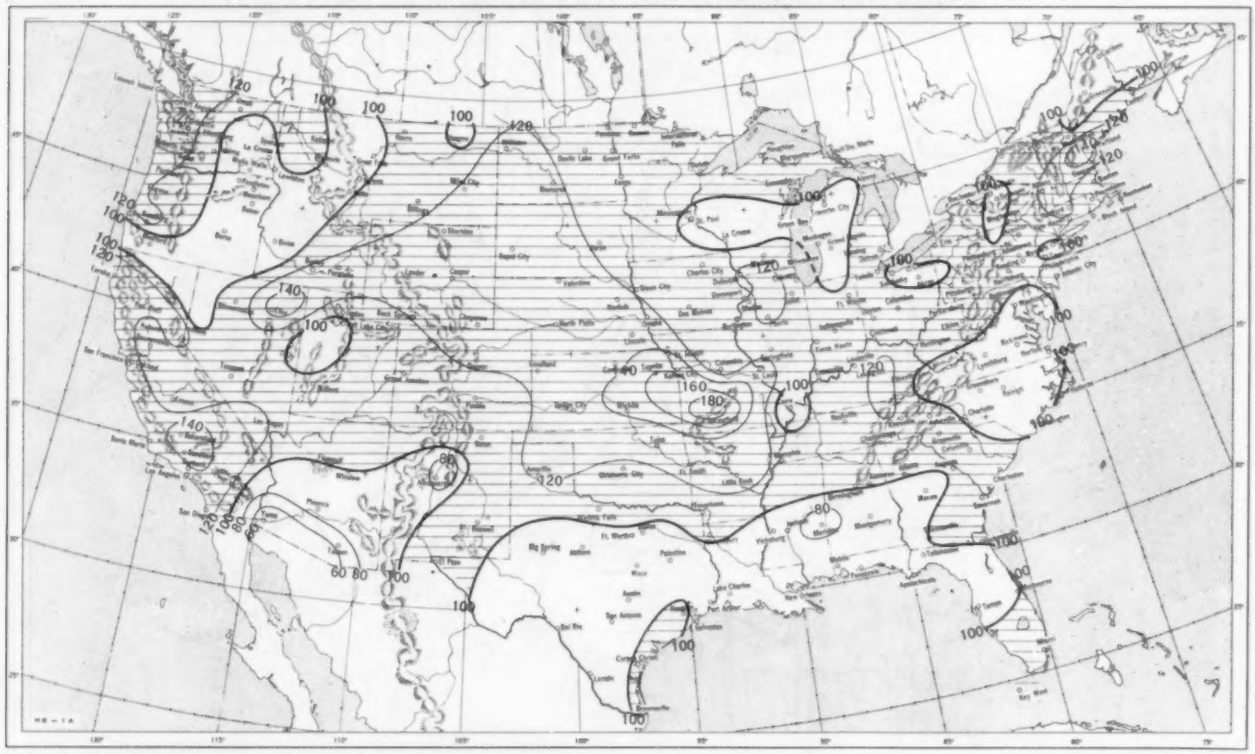


Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, June 1955.

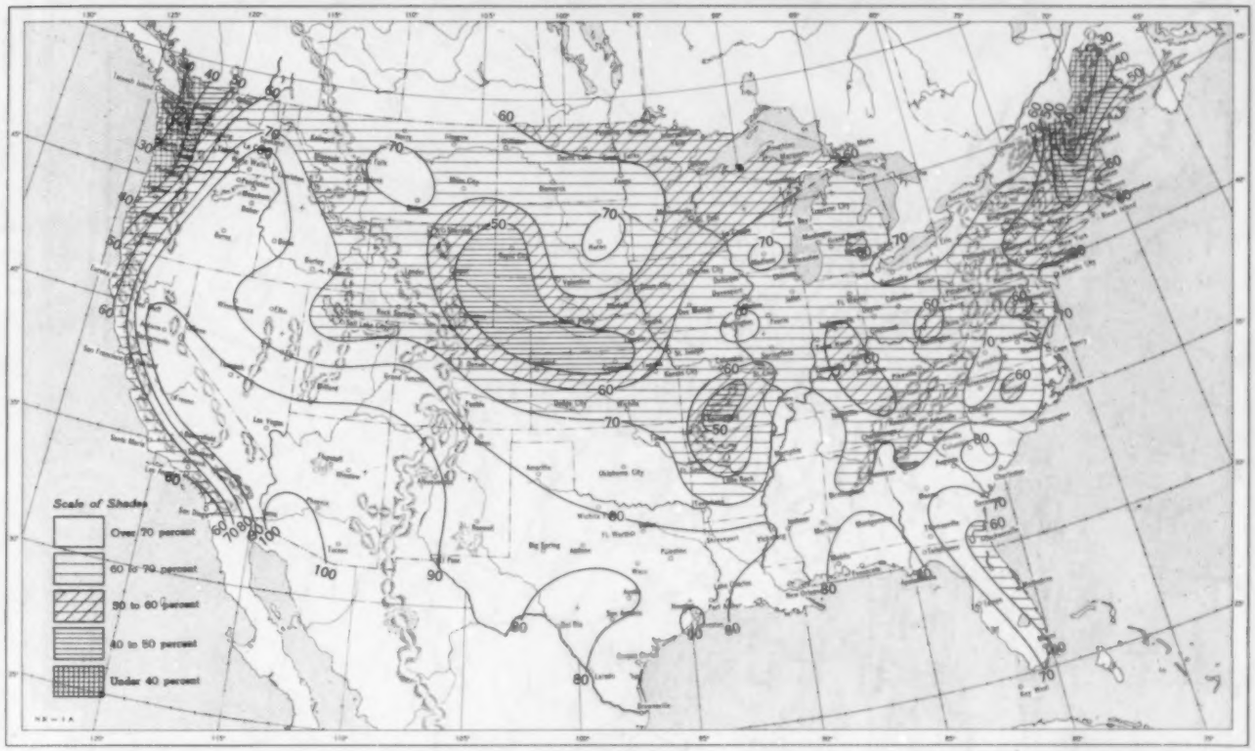


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, June 1955.

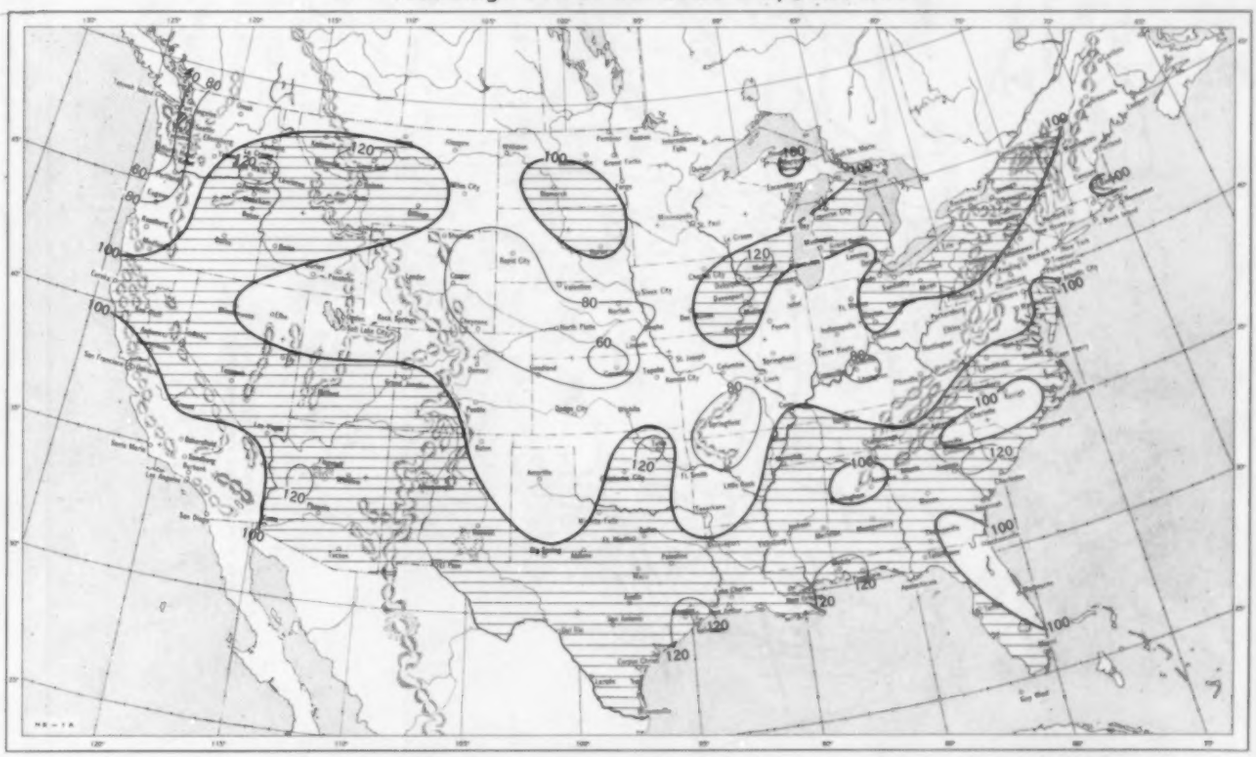


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, June 1955.



B. Percentage of Normal Sunshine, June 1955.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, June 1955. Inset: Percentage of Normal Average Daily Solar Radiation.

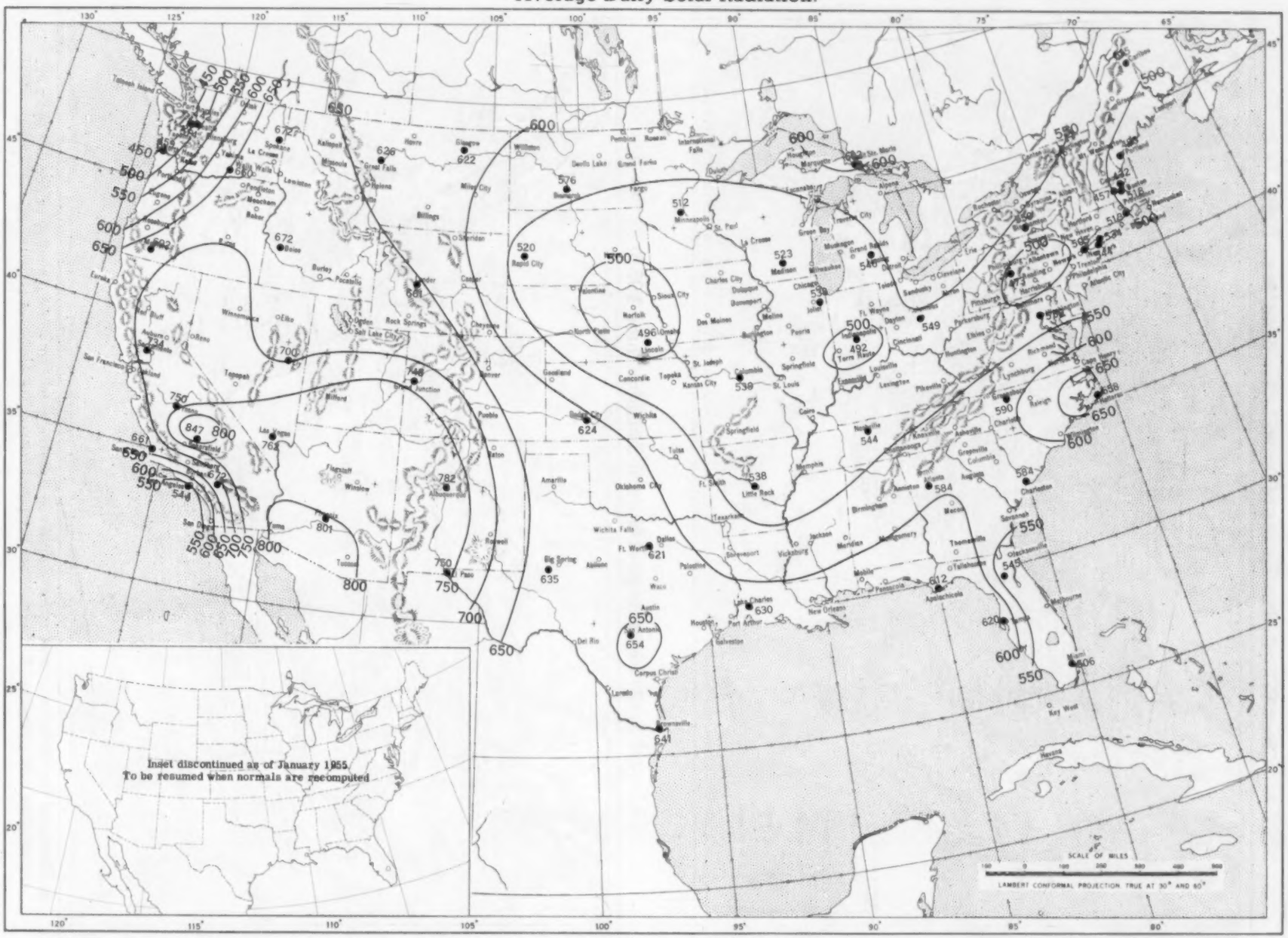
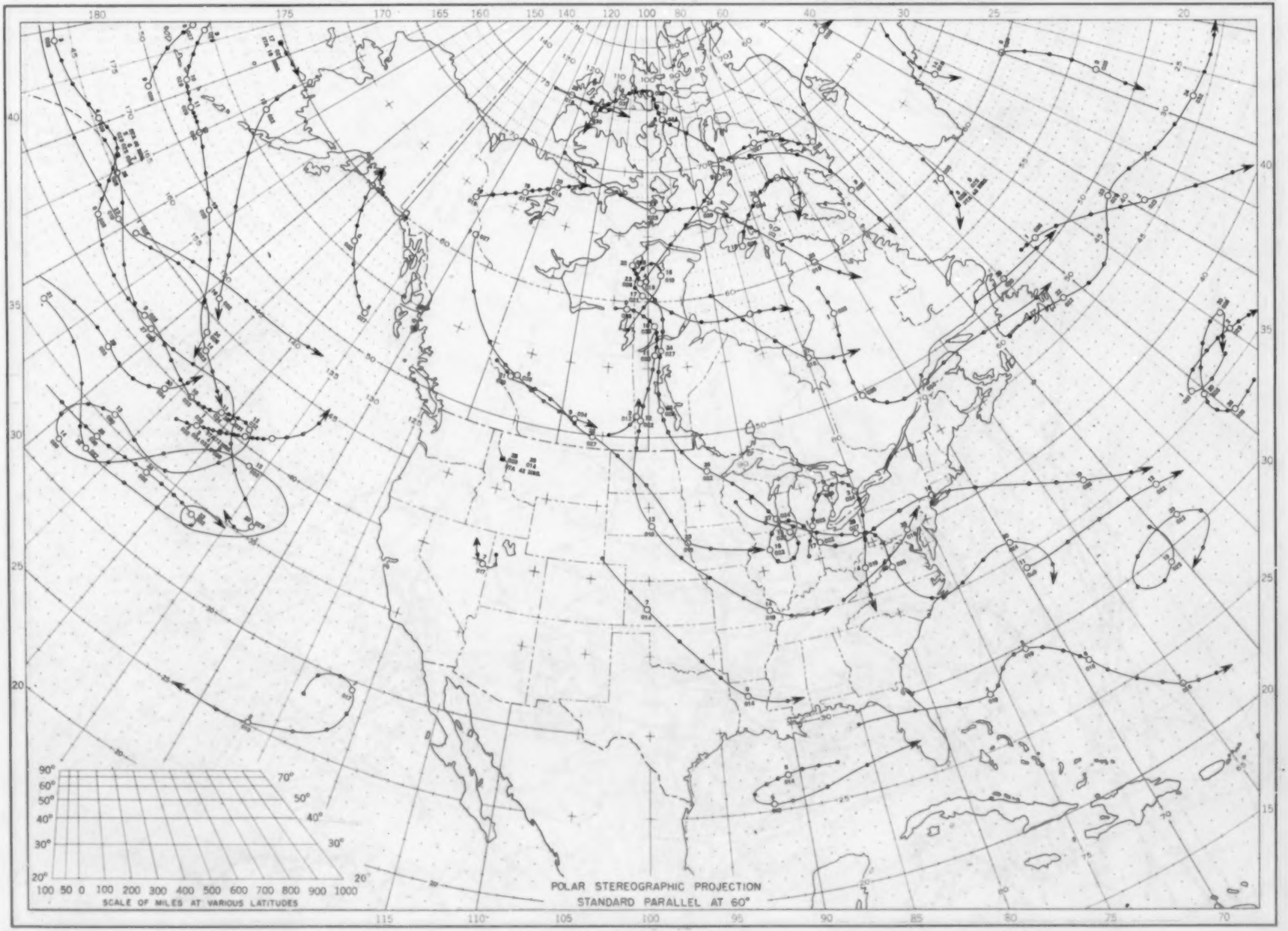

Inset discontinued as of January 1955.
To be resumed when normals are recomputed
SCALE OF MILES
LAMBERT CONFORMAL PROJECTION TRUE AT 30° AND 60°

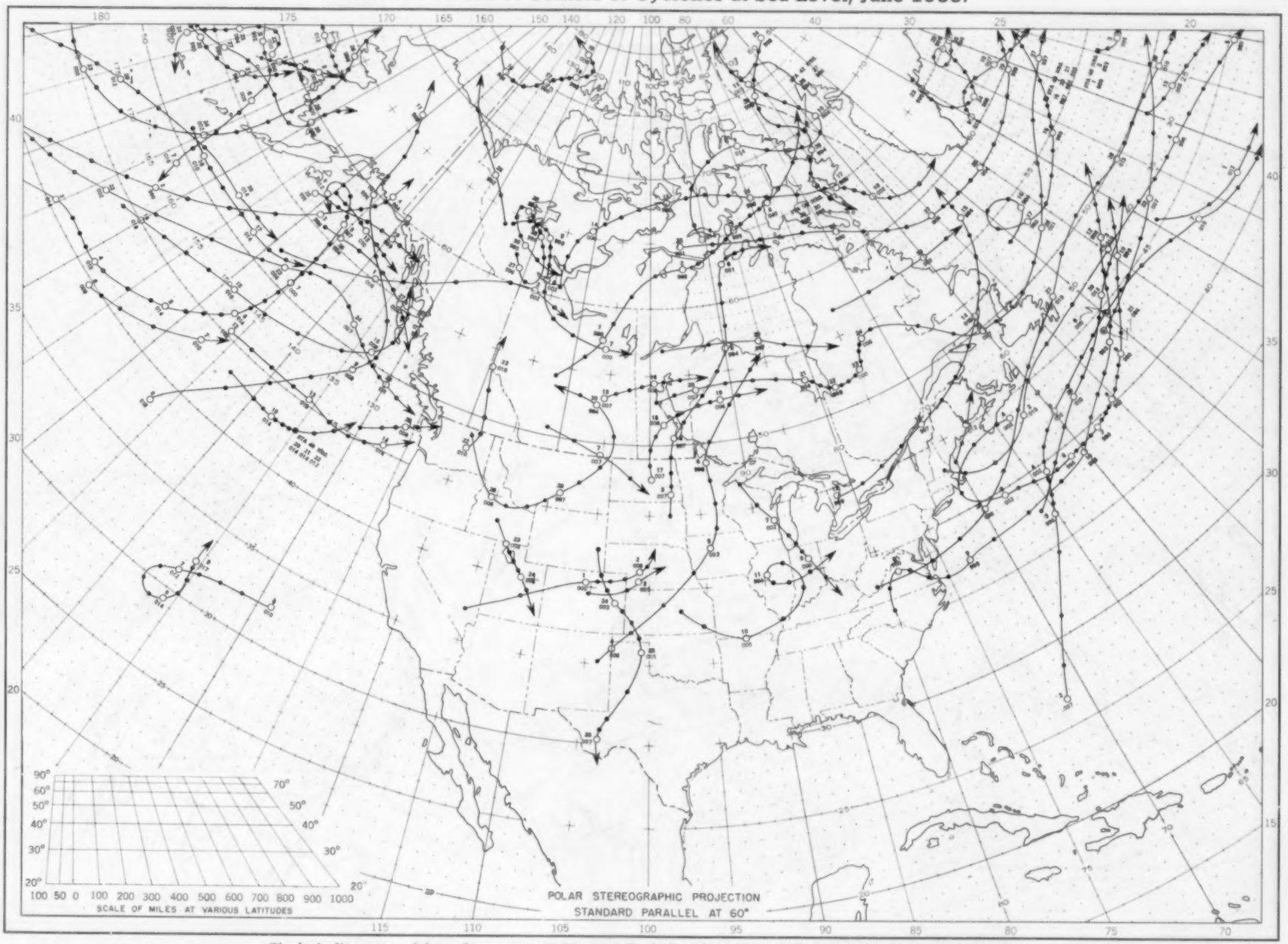
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, June 1955.



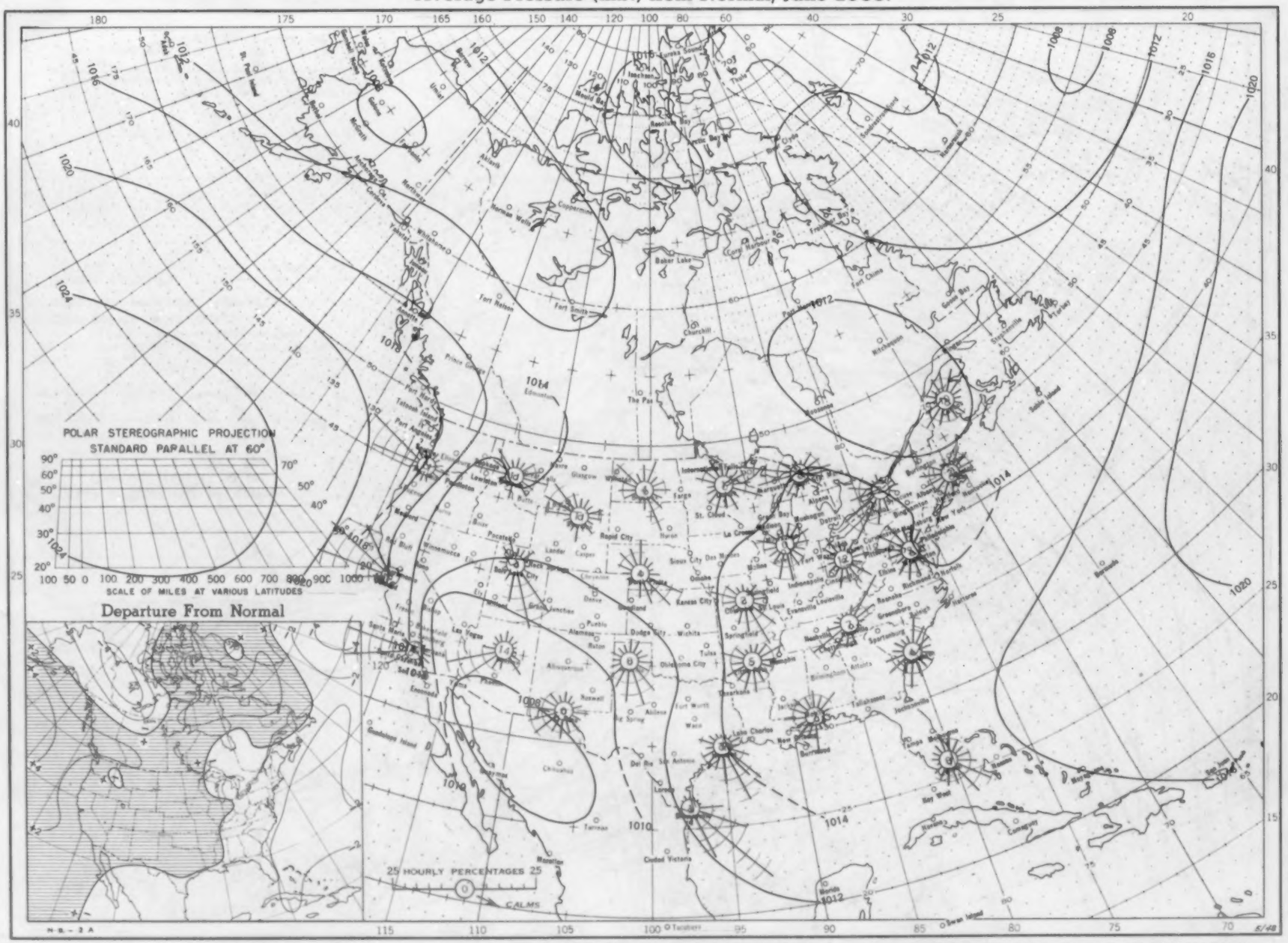
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, June 1955.


SCALE OF MILES AT VARIOUS LATITUDES
100 50 0 100 200 300 400 500 600 700 800 900 1000
POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°

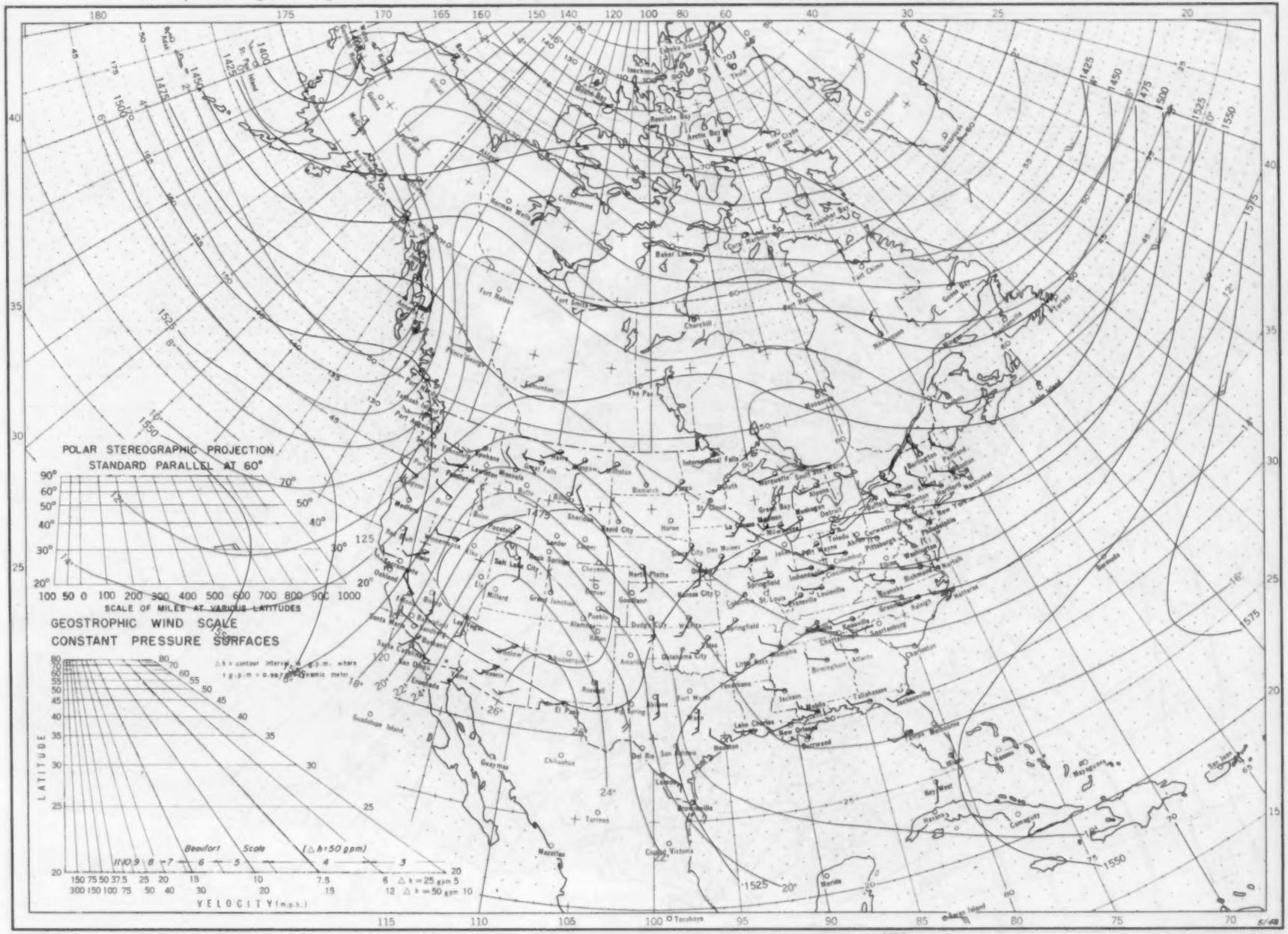
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, June 1955. Inset: Departure of Average Pressure (mb.) from Normal, June 1955.



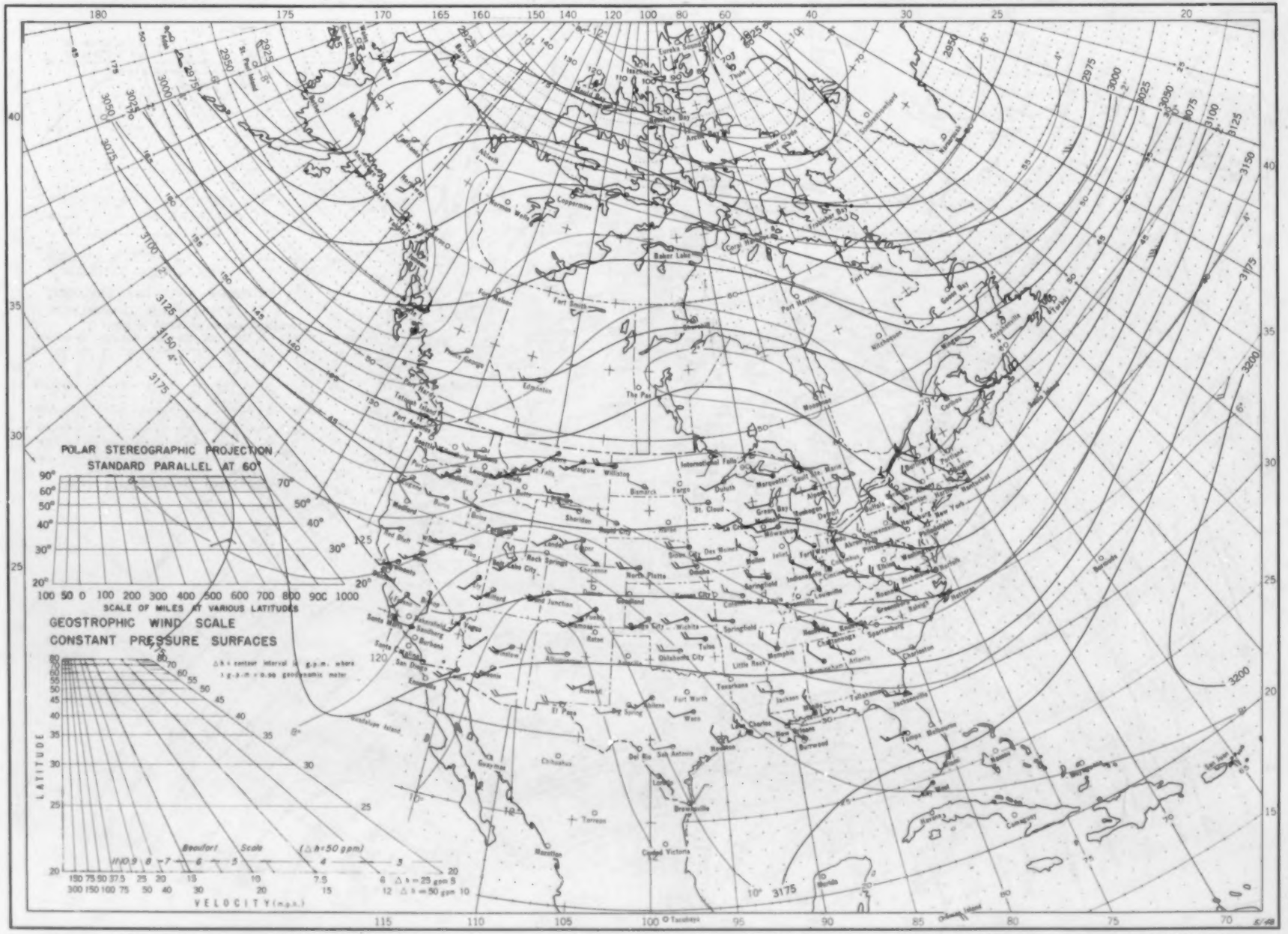
Average sea level pressures are obtained from the averages of the 7:30 a.m. and 7:30 p.m. E.S.T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), June 1955.



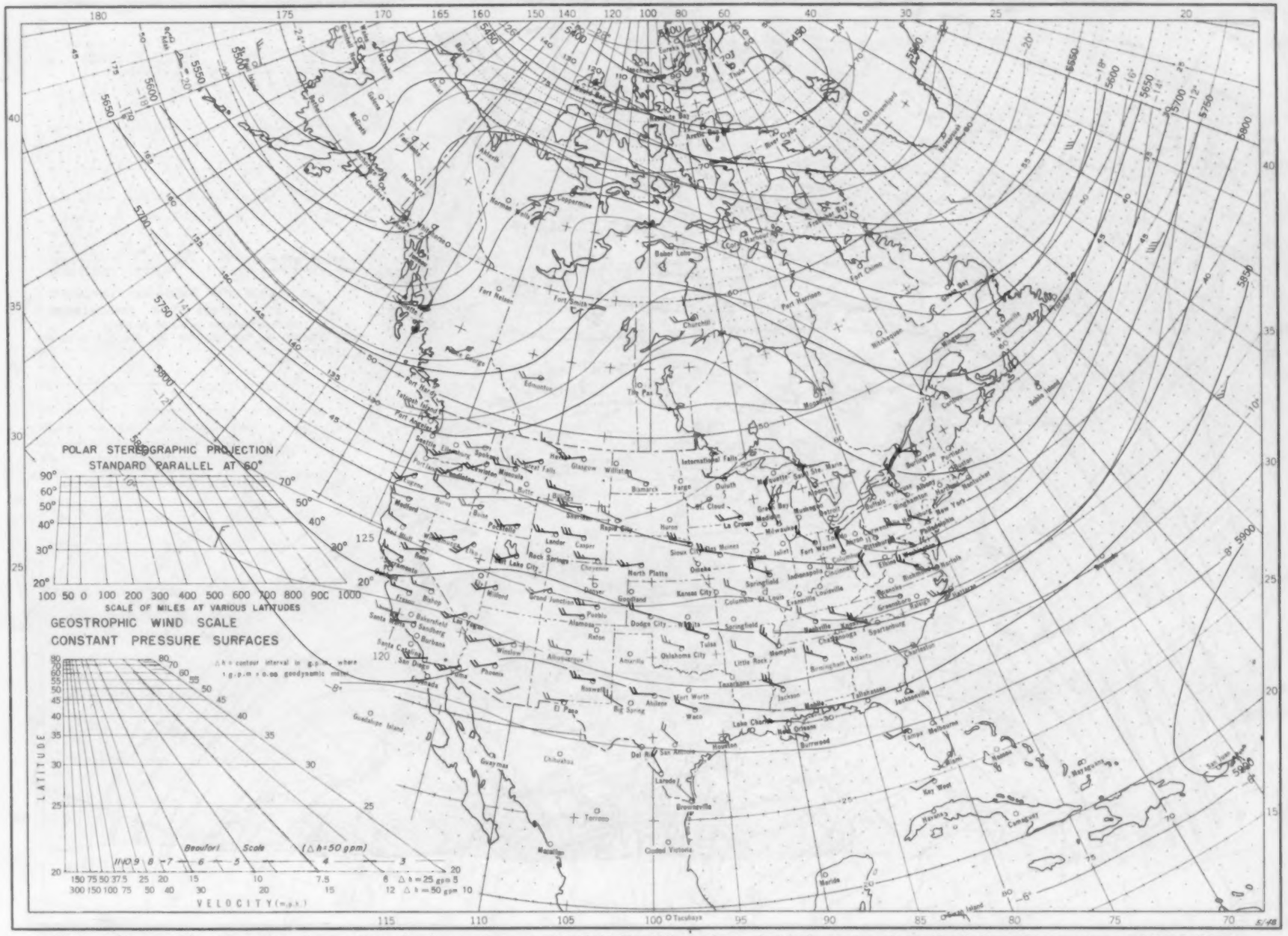
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m.. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), June 1955.



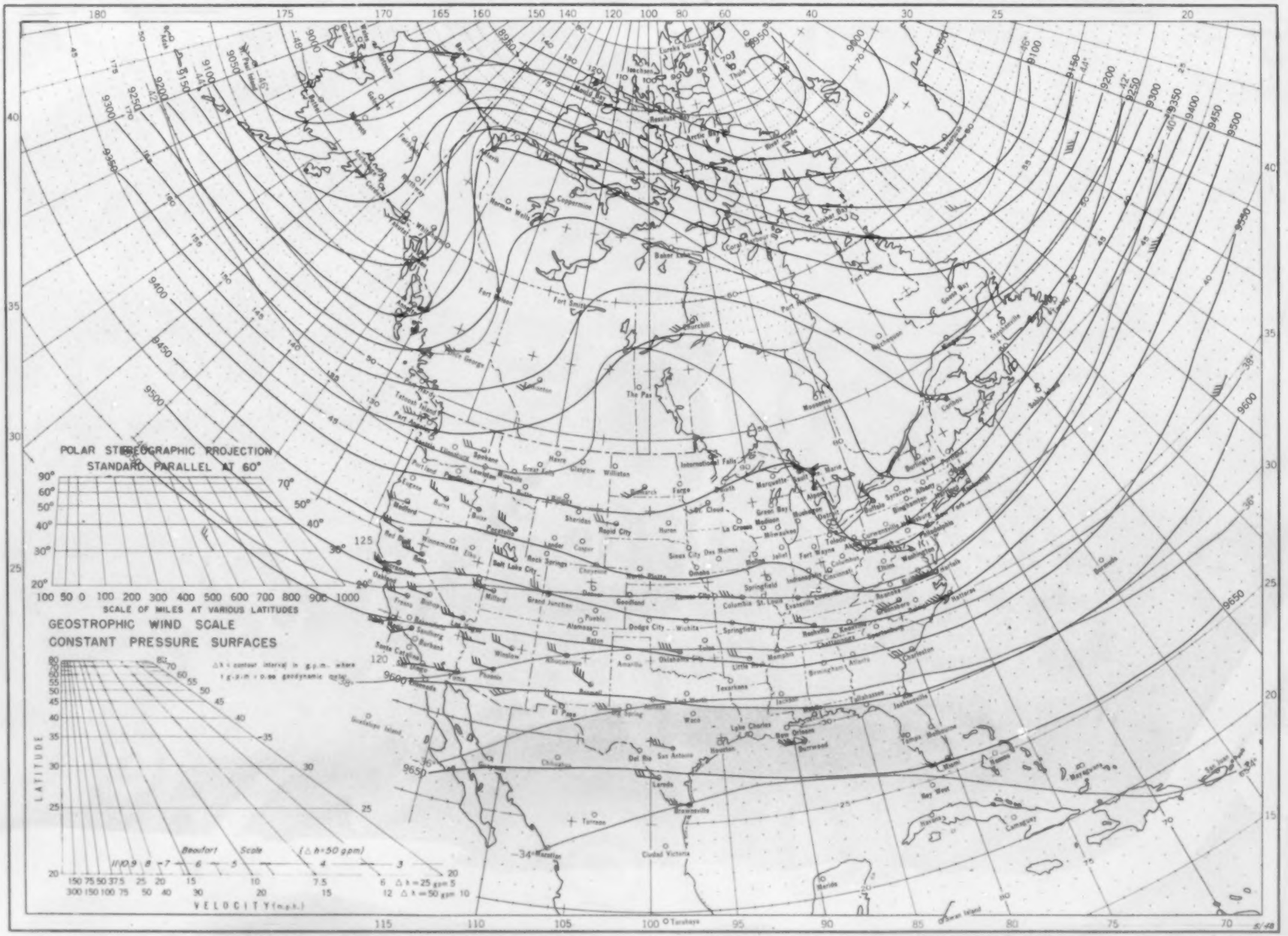
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C. at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), June 1955.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. those shown in red are based on rawins at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; Wind barbs indicate wind speed on the Beaufort scale.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), June 1955.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. those shown in red are based on rawins at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; Wind barbs indicate wind speed on the Beaufort scale.